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Protocols for 3D Visualization as Alternative Mitigation and Public Interpretation

Brian Crane, Versar, Inc.

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1.0 INTRODUCTION

1.1 Use of 3D Visualization in Cultural Resources Management

1.1.1 Introduction

3D visualization of cultural resources is growing in popularity, especially for recordation of the built environment. 3D visualization may include images and virtual models produced by a number of different technologies. 3D Laser scanning (which directs a laser beam onto a subject and records a distance for a given point), and photogrammetry (which produces a 3D model from a series of overlapping photographs) are popularly used to record objects, buildings, and landscapes. Polygonal CAD modeling uses software to model subjects that may or may not be extant. However, there isn't a consistent understanding among potential users and stakeholders about the possibilities and limitations of these technologies. The technology selected for a given project should reflect the intended use. The intended audience for project products needs to be given careful consideration, along with the preservation purpose. End uses need to be considered up-front, as this will determine the most applicable technologies as well as appropriate data transformations and workflows. Consideration also needs to be given to level of effort, distribution of end products, access, sustainability and digital archiving.

This report reviews technologies currently used in the 3D visualization of cultural resources and suggests protocols and best practices that DoD cultural resources managers may wish to follow in designing and implementing visualization projects. Section One describes the sorts of cultural resources projects that may benefit from 3D visualization. Section Two describes some of the most popular recordation and modeling technologies currently in use. Section Three reviews a range of end products that these technologies can produce. Section Four discusses project design and implementation including selecting the technology that best supports the planned end products, user access, as well as considerations for project documentation and archiving. Section Five summarizes the findings into applicable protocols and best practices. Section Six describes the two demonstration visualizations carried out at the Marine Corps Barracks in Washington, DC, and at Marine Corps Recruit Depot (MCRD) Parris Island, SC.

1.1.2 Recordation/Documentation

3D visualization techniques can be employed in a variety cultural resources recordation tasks at different scales and in support of the inventory and recordation requirements of Sections 106 and 110 of the National Historic Preservation Act (NHPA). These include mapping of archaeological sites and features, recording individual objects, buildings and structures, and recording whole landscapes. Because accuracy and precision are valued in recordation carried out for historic preservation purposes, especially for resources that are endangered in some way, laser scanning, photogrammetry and other optical methods are frequently employed for this. Laser scanning and photogrammetry produce highly detailed models of the resources recorded, however, the file sizes may be very large, may require expensive proprietary software to view, and may require additional manipulation or processing to meet some recordation standards. For example, there is no fully automated way to produce measured line drawings, a critical element in HABS/HAER/HALS projects.

1.1.3 Condition Analysis and Building Information Modeling

The use of 3D visualization technologies in Building Information Management (BIM) systems can greatly facilitate historic building assessments and life cycle management. The National Building Information Model Standard Project Committee defines BIM as “a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition” (National BIM Standard – US n.d.). BIM software allows users to build models of buildings that store information related to materials and other functional characteristics associated with 3D modeled building elements. Converting 3D point clouds or polygon meshes to 3D vector models is especially important for using these data to support BIM applications.

1.1.4 Assessing Effects

Assessing the effects of an undertaking on a historic property under Section 106 of NHPA and 36 CFR 800 can be facilitated through the use of 3D visualization, particularly if the potential effects are visual. New construction, demolition, landscaping or other changes can be modeled virtually to allow for a visual assessment of potential impacts. This can also allow for preparing and demonstrating design alternatives intended to lessen or mitigate adverse visual effects. Virtual models can be readily shared with the public or other stakeholders through a website or other means.

Virtual view-shed analysis can be assisted effectively using 3D tools, especially in a GIS environment. GIS software, such as ESRI's 3D analyst, can project the area from which new construction might be visible. This or other 3D visualization software can be used to create detailed renderings of what the view might look like for interpretation to the interested public or other stakeholders. A 3D model can be rendered both from the perspective of the new development or from the vantage of historic properties that might be affected, thus allowing for a virtual evaluation of those effects. This model can then be revised to reflect modifications to a project design that emerge during consultation with project stakeholders, thus facilitating the process.

1.1.5 Research and Analysis

3D recordation techniques have been successfully used to identify and map previously unidentified archaeological sites and landscapes. A laser scanner mounted on an aircraft has the ability to record features on the ground beneath forest canopy otherwise not visible in aerial photographs. It is able to do this by directing a laser beam towards the ground millions of times; while many of those instances will be reflected back by leaves or branches, enough will penetrate past the tree canopy to reach the ground and reflect back. Examples include mapping large urban areas in Mesoamerica (Chase et al. 2013 and Fisher and Leisz 2013). Software tools are available that can help filter out tree canopy as well as identify features conforming to a particular geometrical pattern, such as the effigy mounds at the Sny Magill Mound Site in Iowa (Figure 1.1, Riley 2012). Although not as useful as laser recordation in forested areas, aerial photogrammetry has also been successfully employed to record and map archaeological features and landscapes.

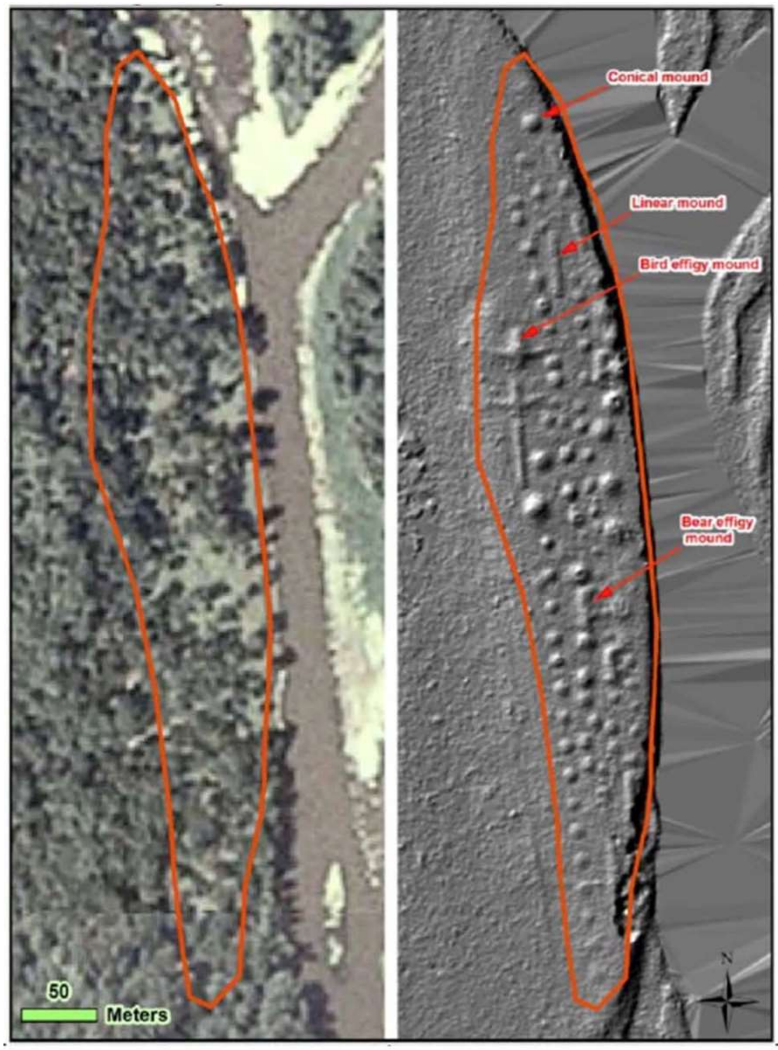

Figure 1.1: The Sny Magill Mound site, in Effigy Mounds National Monument as seen in aerial photograph (left) and LiDAR BE DEM hillshade image (right) (Riley 2012).

Beyond recordation of extant features, 3D visualization offers the possibility to reconstruct features of the landscape no longer present. Such virtual reconstruction of past sites and landscapes enables analysis of those sites in a way not possible otherwise. Possibilities could include exploring historic lighting conditions or historic viewsheds. At the site of Civil War Fort Ethan Allen in Virginia, it was possible to use a virtual model of the fort to reconstruct the location of historic features seen in period photographs but not included in period maps or plans of the fort, even though no extant geographical features are visible in the photographs. The model used reconstructions of buildings shown in both period photographs and engineering plans situated on known topography to estimate probable camera positions. This in turn suggested the location of a signal tower whose location was otherwise indeterminable (Figures 1.2 and 1.3; Crane and Owen 2014).

As a starting point, we made initial estimates on the probable location of cameras used to take known Civil War era photographs based on the quartermaster plans of the fort and associated barracks. Looking over the plan, it appeared that the best candidate for the building shown at the base of the signal tower was a building more or less by itself shown in the lower center of the quartermaster plan, with camera positions 2 and 3 nearby. Then we placed virtual cameras in corresponding locations in the virtual model to see if those vantage points could produce images broadly similar to the historical photographs. These images agreed very well with the model results.

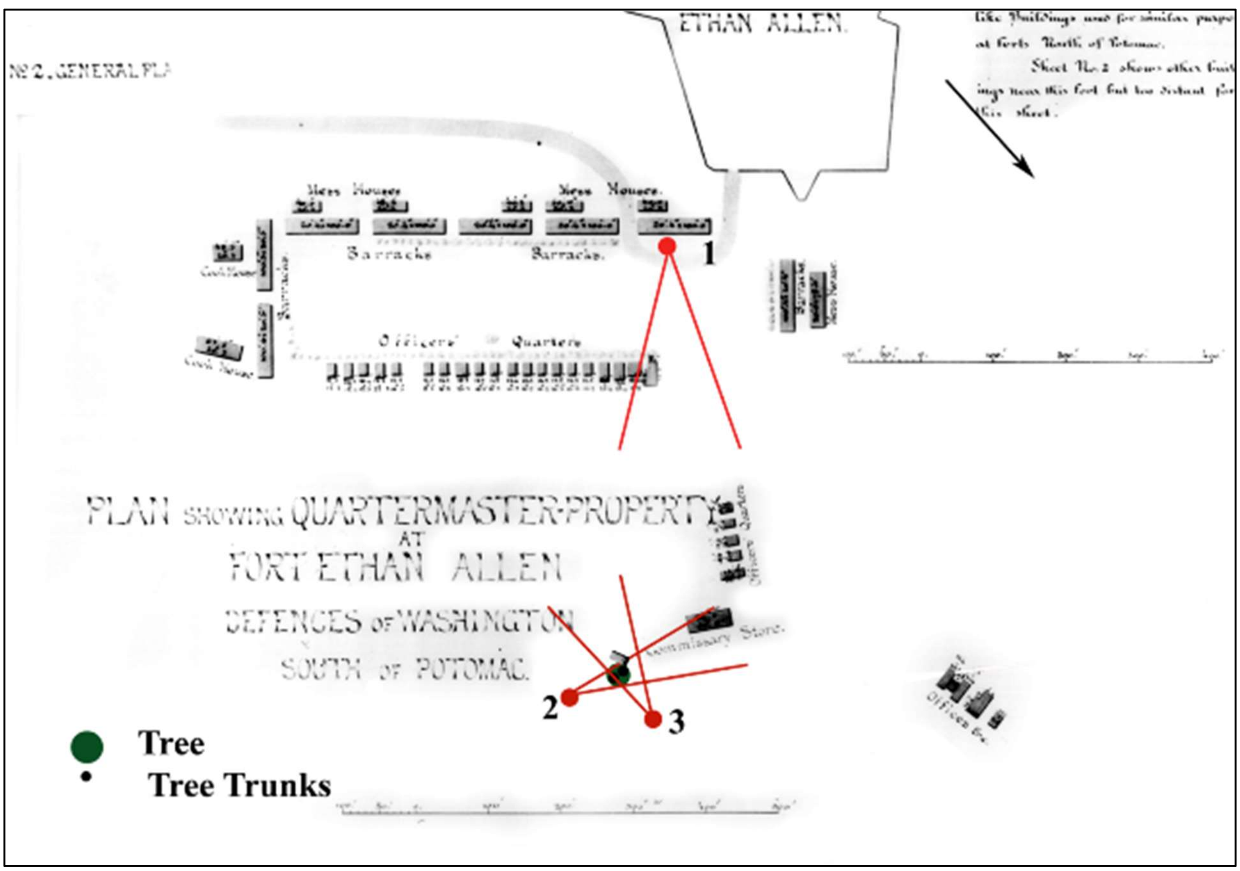

Figure 1.2: Possible historical camera positions indicated on Civil War era engineering plan of Fort Ethan Allen.

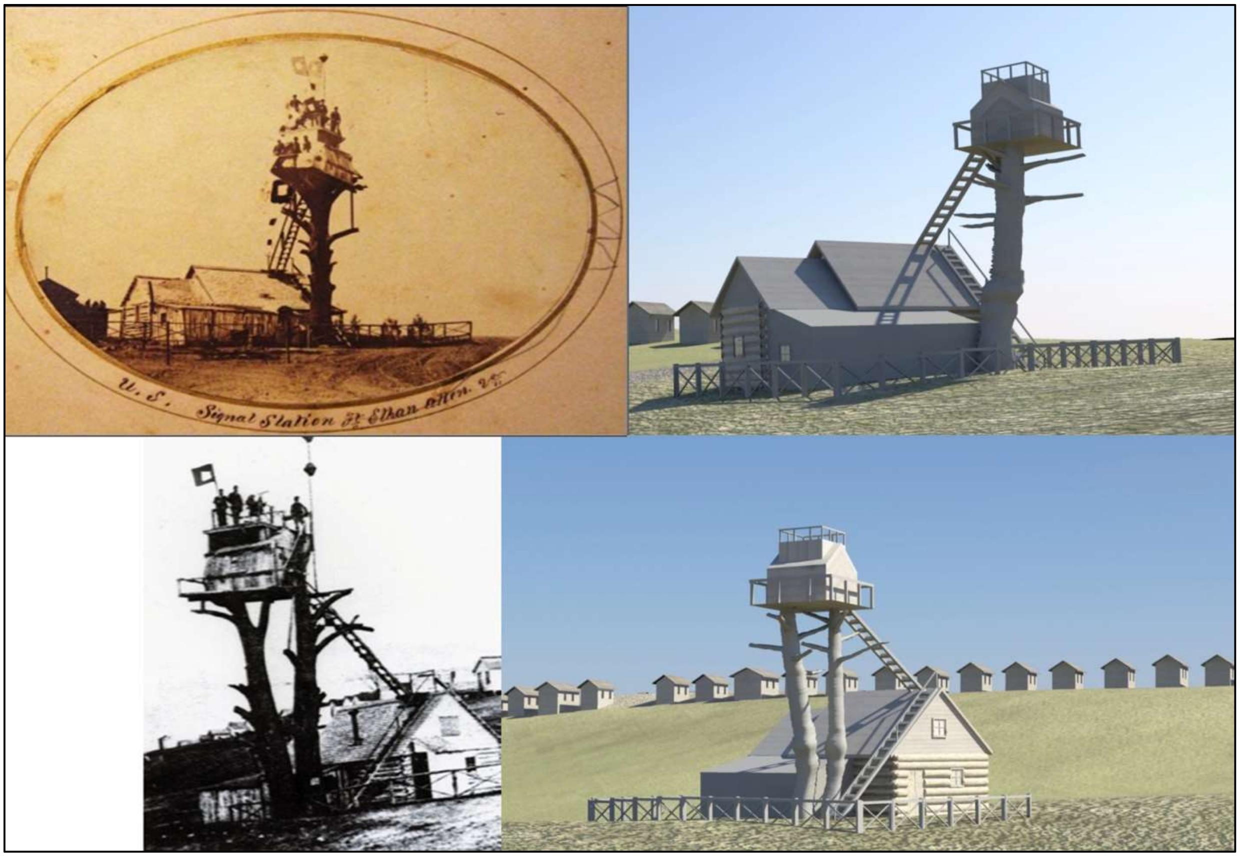

Figure 1.3: Signal station at Fort Ethan Allen, VA, reconstructions and period photographs (camera positions 2 above, and 3).

1.1.6 Interpretation

Lastly, 3D visualization can be used as a vehicle for public interpretation. This may be particularly appropriate as a component of alternative mitigation associated with adverse effects findings, or as a means of making inaccessible historic properties on military installations virtually available to the public. In many cases, especially in areas where contemporary development has obscured or destroyed historic features of the landscape, it can be very difficult for visitors to get any sense of how the landscape may have appeared in the past. The Union fortifications that once ringed Washington, DC during the Civil War are a case in point. The locations of these fortifications have now been overwhelmed by 20th-century suburban development. Little remains of the fortifications themselves, and the surrounding landscape is no longer identifiable (Figure 1.4). Such recreations can be done as a component of alternative mitigation, or other public outreach requirement (Figure 1.5). These images can be static 2D renderings of 3D models, or reproduced as a component of more interactive media (e.g. Unity game, 3D pdf, virtual immersive environment).

Interactive media offer the most immersive potential experience for a user to experience a 3D digital model or recreation of a historic site. There are a number of technologies available to support varying degrees of immersion and interactivity. For this project, panoramic renders were generated from multiple points within the 3D model of a recreated Fort San Felipe. This allows a viewer to virtually look around 360 degrees from selected vantage points. Creation of interactive environments using a game engine like Unity allows for a more interactive experience. Unity is a free game engine that allows a developer to import 3D objects into an environment that a user can then experience as a virtual character, virtually "walking" around the virtual environment, and interacting with the environment as programmed in the game engine. For example, a user on encountering a feature of interest within the environment might click on that feature and be given more information about it. The University of Arkansas has a virtual model of recreated portions of Pompeii that can be explored by users online: http://pompeii.uark.edu/DigitalPompeii_Content/index.html. Exploration requires a web browser with the free Unity plugin enabled, and smooth play is dependent on internet connectivity and the user's computer resources. Virtual environments will be discussed further in Section 3.6.

Figure 1.4: Aerial photograph of Fort Ethan Allen Park, Arlington County, Va.

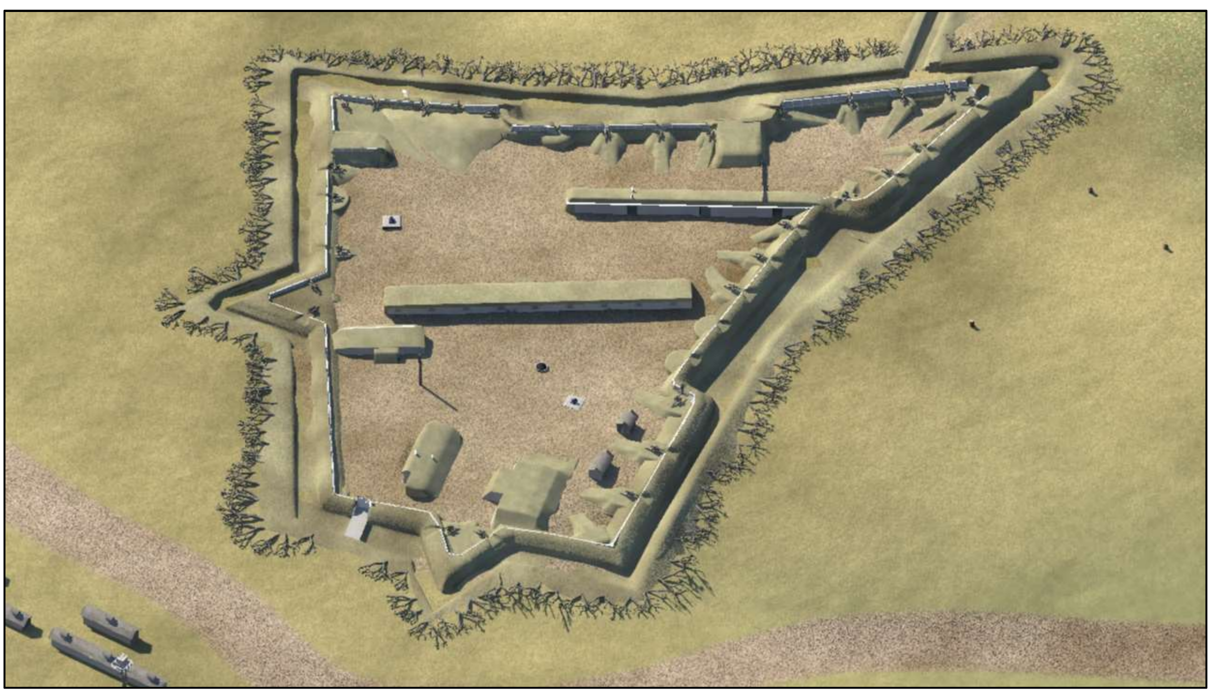

Figure 1.5: Virtual reconstruction of view in Figure 1.4 as it may have appeared during the Civil War.

2.0 Review of 3D Visualization Technologies

2.1 Optical Recordation Technologies

2.1.1 Photogrammetry/Structure From Motion

Photogrammetry refers to the process of generating a 3D model from a series of digital photographs. "The formal definition of photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena" (Matthews 2008). In photogrammetry, a series of overlapping photographs of a subject is taken from differing vantage points. Computer analysis aligns the images taken, and triangulates the distance between the subject and the camera based on the camera's known lens parameters and the apparent changes in the camera's relative position to the subject from one photograph to the next (Figure 2.1). It is used for both long range mapping applications (using aerial orthophotography) and short-range applications for recording buildings, archaeological features, and individual objects.

Computer applications that can produce 3D models from overlapping 2D imagery first use this triangulation to produce a point cloud. A point cloud is a representation of points in 3D space that comprise the model. It is then possible to produce a mesh, a continuous surface connecting all of the points in the cloud. Further processing produces a color texture file that is mapped to the 3D mesh surface. In the example above in Figure 2.1, photographs of an interior fireplace at the Marine Corps Barracks are first aligned and a point cloud produced (upper left). These points are then used to generate a dense cloud (below left), and then a mesh (above right). Finally, the photographs are used to produce a detailed texture mapped to the mesh (below right).

Figure 2.1: Photogrammetry of Fireplace in Marine Corps Barracks Building 8, Washington, DC.

Photogrammetry can now be done with relatively inexpensive digital cameras and low-cost software. As of this writing, a standard license of Agisoft Photoscan can be purchased for less than $200 (a full license that supports georectification of aerial imagery costs $3,499). While any digital camera can be used, the better the camera and the higher the resolution, the better the results will be. Software and basic techniques are relatively easy to learn, though finer points and more complex subjects benefit from greater experience. Photogrammetry is clearly dependent on lighting conditions, and may have difficulty with certain kinds of surfaces, especially flat surfaces, or highly reflective surfaces like glass. Such materials may benefit from advance preparation, such as covering windows, or dusting black surfaces. Complex subjects may require multiple sets of photographs to capture details. Multi-story buildings may require imagery taken from cranes, adjacent rooftops, or from the air. Some tips for taking photographs for photogrammetry include making sure the images are in focus, are properly exposed, don't exhibit lens flare, or overly dark shadows (Blizard 2014). It can also help to introduce a known scale into the scene in order to be able to use the resulting model to make virtual measurements (Georgia O'Keeffe Museum 2012).

It should be noted that photogrammetry processing software packages often produce proprietary file formats: care should be taken to save to more portable or open source formats. Whether in an original proprietary format, or exported into a more widely used file format, 3D point clouds or meshes can only be viewed with specialized software, and by themselves have limited use. They can, however, be used to support a variety of further applications (Revit, 3D pdf, still image renders, animations, game platforms). Models exported to 3D pdf format can be viewed with the free Adobe Reader. More information about file formats and integrating with additional applications can be found in Sections 3 and 4.

2.1.2 Laser Scanning

Laser scanning refers to the practice of measuring the distance to an object by projecting a laser beam on it and using the collected data to construct a 3D model (Figure 2.2). Like photogrammetry, the technology is used at many scales, from scanning small objects to buildings or structures, to whole landscapes. As applied in remote sensing, it is often called Lidar (and spelled variously: Lidar, LIDAR, LiDAR). Lidar is sometimes said to refer to light detection and ranging, while the Oxford English Dictionary states that it was originally a portmanteau of light and radar. Wavelengths used in Lidar range from ultraviolet to near infrared, and are selected to suit the target. Distance is measured in one of three ways: time of flight (measuring the time it takes for the laser beam to reach the object and be reflected back); phase comparison (light of known wavelength and phase is projected onto an object, and compared to the phase of the light reflected back), and triangulation, using light from two sources to measure distance (Barton 2010).

Processing the data initially produces a dense cloud of points in 3D space based on the distance from the instrument to the object for each instance recorded. This point cloud can then be converted into a mesh surface, and a color texture mapped to that surface. This process records color at points, rather than across the body of the subject. Additional computer processing is necessary to generate UV mapped texture (e.g. with MeshLab). A UV mapped texture is a 2D texture that has been mapped onto a 3D surface (U and V are the axes on a 2D surface).

Figure 2.2: Laser recordation performed by Versar, Inc. at Panther Cave, TX.

2.1.3 Other Recordation Methods

Photogrammetry and laser scanning are probably the most commonly used technologies for digitally recording cultural resources in 3D. Other methods of creating 3D imagery that have been used in heritage management include Reflectance Transformation Imaging (RTI) and Structured-Light 3D Scanning. RTI involves taking multiple photographs of a subject from a fixed position, but shining a light onto the subject from multiple known directions. Computer software analyzes differences in the shadows of the collected images to create a digital model of the original subject. “RTI was invented by Tom Malzbender and Dan Gelb, research scientists at Hewlett-Packard Labs. A landmark paper describing these first tools and methods, named Polynomial Texture Mapping (PTM), was published in 2001" (Cultural Heritage Imaging 2016). RTI results allow for the user to enhance subtle surface details, and is sometimes used to help read carved inscriptions, or subtle surface differences on manuscripts. Structured-Light 3D Scanning differs from RTI by projecting a known geometric pattern onto a surface of unknown shape, and recording the resulting distortion with a digital camera. Software analyzes the resulting deformation of the known pattern, and interprets the surface in three dimensions. Technically, this method is actually 2.5 D rather than full 3D since it can only work with surfaces. In order to use this method to prepare a full 3D model, multiple surfaces would need to be combined. In addition to the resolution of the camera, accuracy is limited by the size of the pattern (Center for Bits and Atoms 2010).

2.1.4 Comparisons

Optical recordation methods like laser scanning and photogrammetry can produce highly accurate models. However, it is not necessarily true that laser scanning produces more accurate or finer grained results than photogrammetry. There have been studies that have sought to compare the results of laser scanning and photogrammetry. Michael Nulty conducted laser scanning and photogrammetry of a log structure under a National Center for Preservation Technology and Training (NCPTT) grant (Nulty 2013). That study found no appreciable difference in the accuracy of the two methods, though they did notice differences in cost and recordation and computation time. Similarly, another study by Katie Simon and Rachel Opitz, looked at close range scanning, comparing laser scanning, photogrammetry, and structured light scanning (Simon and Opitz 2013). They found that depending on the quality of the camera and the precision of the laser instrument, photogrammetry could meet or exceed the accuracy of the laser. But the authors also looked at how well the different methods helped capture the specific information actually of interest to the investigator. In comparing photogrammetry with a high-end structured light scanner, they found that while both showed high accuracy in the overall size and shape of the object, in one instance, the structured-light scanner was able to more clearly depict stylistic details in the object than the photogrammetry (Simon and Opitz 2013).

Thus, the best technology to use on any given project may vary depending on the subject, the materials, and the goals of the recordation. Virtues of photogrammetry include lower-cost equipment and software. But photogrammetry is more dependent on lighting conditions than laser recordation and will likely have a harder time with foliage obstructions. Photogrammetry can also have difficulty with glass and other highly reflective surfaces. Furthermore, while the basics of photogrammetry can be learned very quickly, there is an art to learning how to take photographs that yield the best results.

2.2 Computer Aided Design (CAD) Modeling

This method of modeling refers to using 3D CAD tools to develop a mathematical representation of a three-dimensional surface either manually, using modeling tools provided by the software, or procedurally by using algorithms. One can create a model of a subject based on non-digital measurements and information, such as as-built drawings, historical photographs, or archaeological data (Figure 2.3). The technique is often used to design new products or engineering plans, but it can also be used to reconstruct cultural resources that are no longer extant. It is not dependent on field conditions, but is dependent on the quality of information available about the subject. These techniques can produce models that are much more efficient in file size than photogrammetry or laser recordation, and so may be a better choice for producing assets for interactive environments such as game engines.

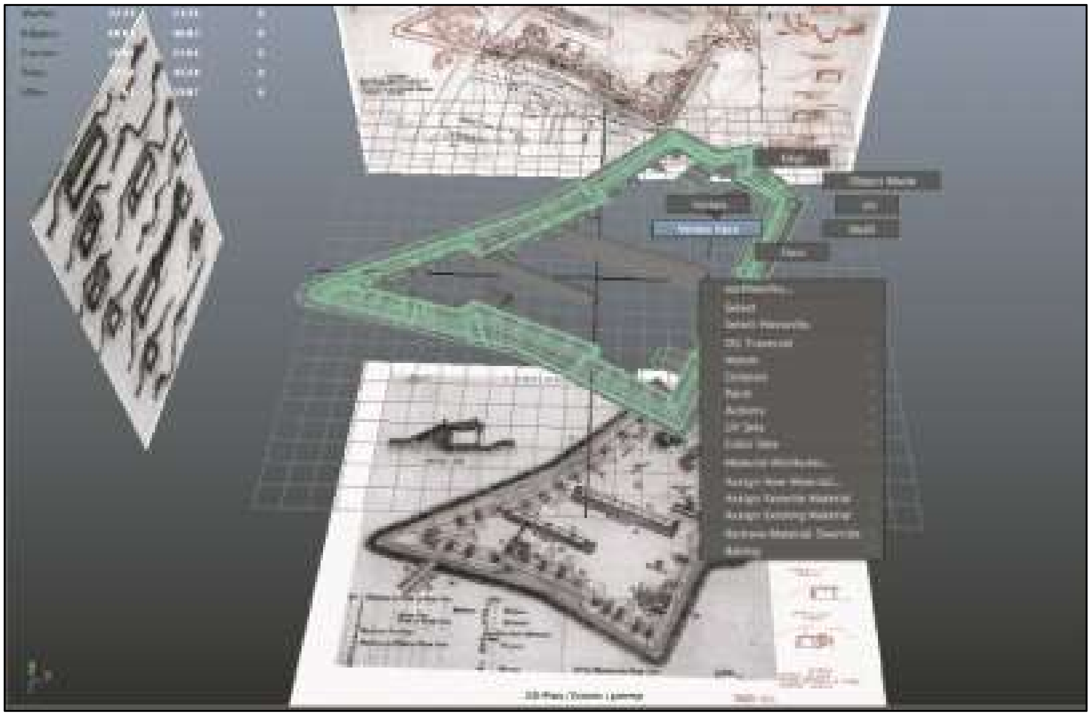

Figure 2.3: Screen shot from Autodesk Maya showing source materials for 3D modeling of Fort Ethan Allen, a Civil War fort in Arlington County, VA.

There is a wide variety of software applications that has been used for historic preservation and related engineering applications. Autodesk products Maya and 3dsMax, for example, provide robust modeling tools as well as tools for animation and rendering. They are popular choices for constructing photorealistic environments for historic site reconstructions, but are expensive. Rhinoceros 3D has become popular with underwater archaeologists reconstructing shipwreck sites. Blender is a free 3D modeling and animation software package produced by the nonprofit Blender Foundation. SketchUp is a popular tool for creating 3D assets for GIS applications, and often used by landscape architects. Autodesk Revit supports BIM applications and is widely used by engineers. There are many others (see https://en.wikipedia.org/wiki/List_of_3D_modeling_software for a partial list). Most of these applications can import and export models in a wide variety of formats as well as produce still renders and animated sequences. Apart from Blender, most of these applications cost several thousand dollars (see Table 2.1). All require a substantial investment of time to learn.

Modeling programs like Maya or 3dsMax include a wide variety of modeling tools. In addition to modeling with polygons (simple geometric shapes), the software also supports non-uniform rational basis spline (NURBS) modeling. NURBS can be useful for modeling objects with curved forms. Modeling applications also support a wide range of particle and fluid effects useful for simulating water, fire, smoke, rain or other natural or man-made phenomena. Programs like Maya, 3dsMax or Blender primarily make use of mouse and keyboard. 3D artists who want a creative experience more akin to sculpting and using a tablet and stylus may prefer applications like Pixologic's ZBrush. ZBrush is technically a 2.5 D application (the user always sees the model from the perspective of a fixed virtual camera, but can turn the model in any direction), and is a popular choice for making human and animal characters along with other organic objects.

There are a number of commercially available BIM software applications including: Bentley AECOsim Building Designer, ArchiCAD, Tekla Structures, Autodesk Revit, and VectorWorks. These are similar to CAD software applications, but allow additional attributes to be stored related to materials, manufacturer's specifications, cost, time, etc.). Industry Foundation Classes (IFCs), which are data structures for sharing information, have been developed by buildingSMART to provide open standards for the exchange of information among different software applications. buildingSMART, formerly the International Alliance for Interoperability (IAI), is an international organization dedicated to improving the exchange of data across different software applications used in construction (buildingSMART 2014).

CAD modeling programs can be used in conjunction with optical recordation techniques to produce powerful visualizations that combine detailed imagery of existing features with virtual reconstruction of missing features. To do this, a point cloud, or more optimally a dense 3D mesh produced by laser scanning, photogrammetry or other optical method, is imported into a 3D CAD application, and then additional materials can be created. This also allows for multiple associated scanned objects to be oriented or reoriented spatially to each other. This is useful in a case where existing elements within a property have been moved, or perhaps removed altogether, but available for recordation at another location. Similarly, BIM software, such as Revit, can import a 3D point cloud generated by laser scanning or photogrammetry. The imported point cloud can then be used as a reference for creating a BIM depicting detailed existing conditions. Some software, such as PointFuse, can automate portions of this effort, but in general, going from a 3D point cloud to a BIM is not fully automated.

Table 2.1: Comparison of 3D Recordation and Visualization Techniques					
Hardware	Cost	Software	Cost	Advantages	Disadvantages
			Photogrammetry		
Digital Camera	$100-$5000 (simple fixed lens camera to high quality SLR).	Agisoft Photoscan, Bundler, 123D Catch, others (see https://en.wikipedia.org/wiki/Comparison_of_photogrammetry_software)	$0 (Bundler) $179 (Photoscan Standard License, $3,499 Professional Edition).	High Accuracy, relatively low costs compared to laser	May be susceptible to light conditions, obstructions, highly reflective surfaces. Accuracy is dependent on camera resolution, focus, and distance to subject (number of properly focused pixels across the subject).
			Laser Scanning		
Laser Scanner	$1,500 (low-accuracy short range) - $100,000 (high accuracy, long range)	Bundled with hardware	NA	High Accuracy	Expensive equipment
			RTI		
Digital Camera and Light Sources	Similar to Photogrammetry, but also need a tripod for the camera, and a moveable light source on a tripod, plus reflective sphere ($370 kit from Culturalheritageimaging.org).	RTIBuilder	Free (http://culturalheritageimaging.org/What_We_Offer/Downloads/Process/index.html)	Offers ability to enhance low relief subjects).	2.5 D, short range, mostly suitable for small objects.

Structured-Light 3D Scanning						
Structured Light Scanner	2.2.1	$163 (Kinect), $100 (Intel RealSense 3D Camera)	Free 3rd party software for low-density point clouds from Kinct. Intel RealSense 3D Camera developer kit comes with software.	Free or included with hardware.	Low costs	2.5D Short Range, suitable for small objects, software may only generate sparse point cloud.
CAD Modeling						
Computer	NA		Many applications exist: Maya, 3ds Max, Blender, Revit, Rhinoceros, etc. (see https://en.wikipedia.org/wiki/List_of_3D_modeling_software).	$0 (Blender) to $4,300 (Maya)	Can recreate features no longer extant. Can create BIM	Recordation using CAD technology requires manual measurement and data entry.

3.0 End Products

3.1 Introduction

Software applications that produce 3D models can generate a number of different end products. These differ in size, the level of effort to produce them, the kinds of software and computer requirements needed to view/manipulate them, and the degree of interactivity for the user. The simplest, smallest and least demanding end products are single, still-image renders. They are easily shared, but because they are static, offer the user no opportunity to manipulate them. Video files including simulated fly-throughs of the model are also easily shared and give the user a richer experience, but they are still fixed rather than interactive. Three-hundred-sixty-degree renders created from within a model (such as created for Fort San Felipe for this project) are still easily shared (they can be viewed with any web browser) but provide an additional level of interactivity, since the user can look in any direction. The point of view is fixed, but multiple renders can be linked together through hot links, providing the user the opportunity to jump from vantage point to vantage point. More interactive end products allow a user to manipulate the model in 3D using a viewer designed to display 3D models. The most interactive end products involve creating a 3D environment a user can move through either in a gaming environment or with virtual reality software and hardware.

3.2 Still Renders

Still renders are graphic files that are produced by a virtual camera placed within a virtual 3D space. Most software applications that produce 3D models allow for generating a still image from any vantage point, including orthographic images (images without perspective). Sophisticated 3D applications (such as Autodesk Maya) used in the commercial gaming and entertainment industries support complex lighting effects that can be used to mimic sunlight, artificial lights, shadows, and other related atmospheric effects. Still renders can be simply a view of the model, or may have additional explanatory material layered in (Figures 3.1 and 3.2 of Fort San Felipe).

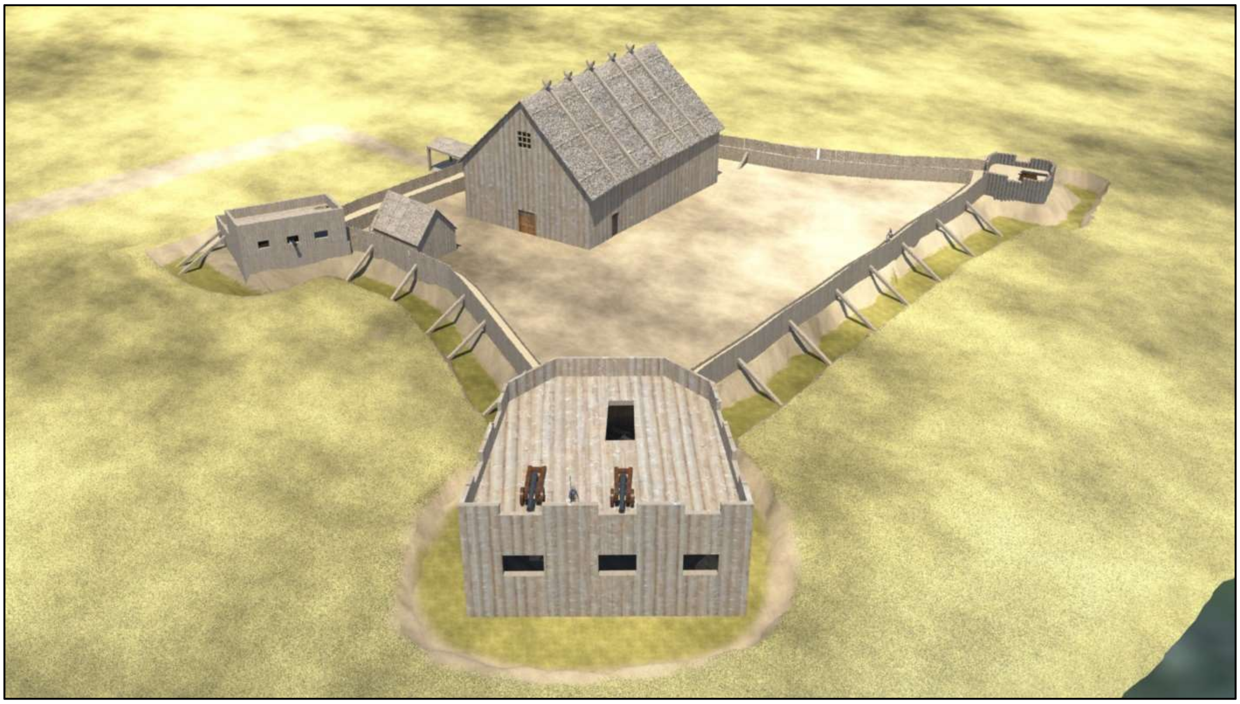

Figure 3.1: Render of the 3D model of Fort San Felipe at the site of Santa Elena for this project.

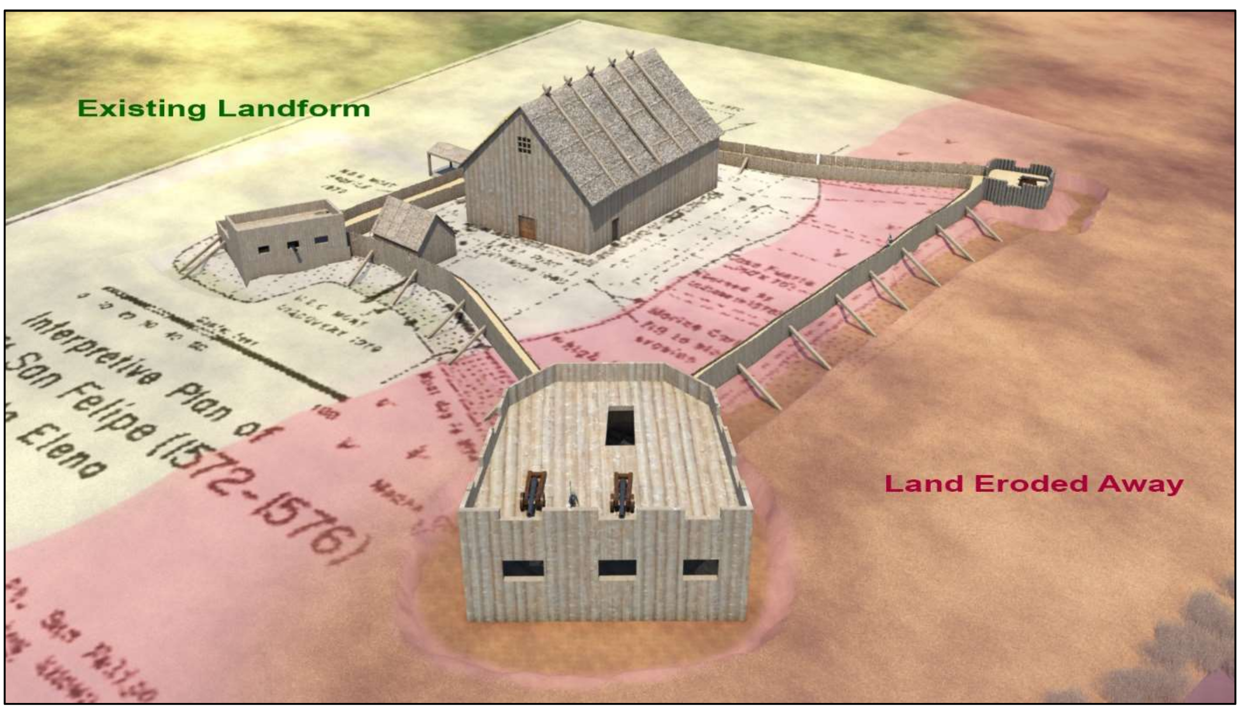

Figure 3.2: Fort San Felipe with archaeological data layered into the image.

3.3 Animated Movie Files

Animated movie files consist of video files that depict motion within a 3D environment for a specific duration. Animations can simply involve a camera moving through a static environment, allowing the viewer to see the model from the viewpoints through which the camera moves, or it can also display elements of the environment itself in motion. This allows for a greater appreciation of the 3D environment while still relying on a static end product (a fixed video file). More elaborate animations can reproduce historical actions taking place within the 3D scene, such as moving people or working machinery. Animating complex objects such as characters or machines requires that the object be "rigged" first to support deformations needed to depict movement. Key frames (specific moments within the animation timeline where the rigged object is in a particular place or deformation) are added to mark key moments in the animation. Software programs like Maya then interpolate the movement between the keyed frames. To produce an animated segment, a software program such as Maya renders individual frames that are then compiled into a single video file by another video program, such as Adobe After Effects. Animated sequences are typically rendered at 24 frames per second, meaning that the number of individually rendered frames can be quite large, depending on the length of the video desired. The compilation software can add additional elements to the video beyond the animation, including sound and explanatory text thus extending the range of interpretation available. Video files can be produced in a wide variety of formats and distributed easily over the internet or made available for streaming from such sites as YouTube or Vimeo. If an animated movie is a desired end product, knowing in advance how it will be distributed may be important if there will be specific requirements for file size, codec or aspect ratio.

3.4 360 Renders

A 360 degree render of a 3D environment involves creating a single static render that includes everything visible from that point in the model. The resulting rectangular file looks very strange by itself (Figure 3.3), but can in turn be transformed into a partially immersive environment through such software as Panorama Studio and viewed with a Web browser. The resulting product produces a partially interactive environment within which the user can look in any direction. It is not a fully immersive environment since the viewpoint is fixed, but multiple such renders can be linked together through hyperlinks so that a user can virtually move from viewpoint to viewpoint. Additional explanatory materials can also be added thus extending the degree of interactivity. The resulting pages can be hosted on a web server, or distributed on CDs or as a download that can be run on a user's desktop.

Figure 3.3: Example of a 360-degree render from within the Fort San Felipe model created for this project.

3.5 3D Viewers

Recordation technologies like photogrammetry or laser recordation typically produce large point clouds or 3D meshes as end products. These files can be made available to users through a variety of free viewer applications.

3.5.1 Point Clouds

Laser scanning and photogrammetry produce 3D point clouds, usually generated with proprietary software and in a proprietary format. However, there are some open-source formats that have been developed to facilitate data sharing. LAS is an open-source binary data file format developed by the American Society For Photogrammetry and Remote Sensing (ASPRS) for the exchange of point cloud data (ASPRS 2012). However, though this file format can be read by a number of applications, most of those are fairly expensive. However there are free and low cost viewers that are available. "FugroViewer is a freeware designed for use with LiDAR and other raster- and vector-based geospatial datasets, including data from photogrammetric and IFSAR sources" (Idaho Lidar Consortium 2016a). Another is the Merricks Mars viewer (Idaho Lidar Consortium 2016b). Unity has also developed a low-cost plugin ($75) for their game engine that can be used to view point cloud data. The plugin will not support using the point cloud as part of an interactive game, but will support viewing the point cloud.

3.5.2 Meshes

A 3D mesh is a polygonal representation of a 3D model, and is often produced from 3D point clouds though additional data processing. "MeshLab is an open source, portable, and extensible system for the processing and editing of unstructured 3D triangular meshes" (Meshlab 2014). Once opened by a 3D mesh viewer, a model can be manipulated by the user to see the model from any angle, or to zoom in or out from particular details. Meshes can be distributed in a variety of file formats, including open source formats like obj files that can be read by a wide range of applications. Some 3D applications (such as Agisoft Photoscan or the SimLab pdf exporter plugin for Maya) can produce 3D pdf files. 3D pdf files can be viewed and manipulated by the free Adobe Reader. In addition, the 3D viewing tools available in Adobe Reader allow the user to make measurements between any two points on the model, provided the model units have been specified in creating the file. There are also third party viewer websites to which models can be uploaded and viewed via a web browser (e.g. https://a360.autodesk.com/viewer). The advantage with this cloud approach is that the user need not install any software. The drawback lies in loss of control over the model in providing it to a third party, and in differences among user's internet access speeds.

A significant amount of effort may be necessary to take point cloud or mesh models generated by photogrammetry or laser scanning into other applications such as BIM software or game engines. There is as yet no automated system for translating a dense mesh into a simpler polygonal model such as would be of use in a BIM, or an architectural line drawing as would be desirable for HABS/HAER recordation. The problem has been approached theoretically, however. One method produces a stylized line drawing by partitioning a mesh into large components that can be cut and layered according to visibility (Eisemann et al. 2009). Meshes can also be segmented based on their surface normals (Ning et al. 2009). Others have advocated preparing a library of standard architectural shapes that can be fitted to a scanned mesh (Murphy et al. 2007). Some applications provide support for separating, grouping and measuring features from a mesh, but the process is largely manual, and requires some knowledge of the object or building. The software firm Arithmetica, Ltd., has developed its Pointfuse software to offer automation of key parts of this workflow (Arithmetica Ltd 2016). As of this writing, the software retails for approximately $2,500.

3.6 Interactive Environments

There are a number of existing and developing technologies that will support adapting 3D visualizations for an interactive user experience. Perhaps the simplest and easiest to distribute are interactive "games" that can either be made available online, or distributed to potential users as a software package they can install on a desktop. Unity is an example of a free game engine that allows a developer to import 3D objects developed in other applications, and create an environment where a user may be able to move around within a model, and virtually touch objects that might then move, or open windows with additional imagery or explanatory material (Unity Technologies 2016). A game engine like Unity can support a wide variety of 3D objects, including large data sets. But if the goal is to distribute the environment to a potentially broad range of users, it may be necessary to produce or modify 3D objects that are very efficient in the way they draw on computer assets. For example, it may be more efficient to include most of the visual information in associated textures applied to simplified geometry than to import objects with very high face counts. For example, a 3D model generated from laser data or photogrammetry can easily contain millions of faces, while the same object might be accurately redrafted with CAD software (e.g. Maya) with only a tiny fraction of that number.

Developments in virtual reality technology offer another potential avenue for 3D visualization of historic sites. In virtual reality, or immersive media simulations, a user wears special stereoscopic equipment that allows them to experience a virtual world in three dimensions, via an immersive CAVE (computer assisted virtual environment) system. One of the interpretive opportunities that virtual reality applications (or augmented reality applications like Google Glass) offer is for a user to visit the physical location of a historic site, and be able to virtually experience what that site may have looked like at different periods in the past. This would be particularly valuable in places that have experienced dramatic changes over the course of history that are difficult for a visitor to appreciate through other means. The Oculus Rift viewer will be available to consumers in late March 2016; pre-orders for the Oculus Rift retail for $599. Developers will be able to use Oculus Utilities for Unity to develop 3D content for use with the Oculus Rift viewer in much the same way as they are developed for desktop or Web applications with the Unity game engine (Oculus VR, LLC 2016).

3.7 Evaluating End Products

Which of the end products described above is best suited for a given project depends on the level of effort available, how accurate or precise the model needs to be, and how interactive the end products will be. Foni at al. (2010) have created a methodology for evaluating 3D visualization projects along 4 axes: how virtual the product is (as opposed to physical), the degree of automation (related to the level of effort for creation), accuracy/precision, and the degree of user interactivity. Table 3.1 includes a list of potential end products incorporating 3D visualizations along with a rating from 0 to 1 (Foni et al. 2010). This gives a sense of how well different end products achieve certain ends and at what cost. Low scores represent low precision, low level of effort, and little interactivity.

Table 3.1: Evaluation of Visualization Technologies (from Foni et al. 2010)

Product	Precision	Interactivity	Automatism	Virtuality
Renderings	0.85	0	0.15	1
Digital catalogs	0.2	0.15	0.7	1
Digital panoramas	0.3	0.4	0.9	1
Real time VR simulations	0.8	0.9	0.4	1
Stereoscopic visualizations	0.7	0.7	0.3	1
Computer games	0.6	0.75	0.25	1
Real time AR simulations	0.5	0.85	0.25	0.5
Augmented movies	0.9	0	0.1	0.5
Semantically supplemented 2D	0.2	0.5	0.65	0.5
Semantically supplemented 3D	0.8	0.95	0.25	1

Renderings refers to static image renderings of a model. Digital panoramas are developed from 360 degree renders, which a user can manipulate, giving the illusion of looking in any direction. Real time virtual reality simulations completely immerses the user in a virtual environment, such as by wearing a helmet and gloves designed to allow the user to manipulate objects within the simulation. A stereoscopic visualization is a static render, but consists of two renders from slightly different perspectives that allow the viewer to experience the model in 3D. Computer games create an environment for a user to explore. Real Time Augmented Reality (AR) simulations differ from VR in not immersing the user completely. The user remains connected to the real world and experiences virtual elements projected onto real ones in some way: Google Glass is an example. Augmented animated movies simply refers to a video file with an animated sequence. Semantically supplemented 2D and 3D representations refer to 2D or 3D products that have additional information for the user, in the form of associated data, text, graphics, sound, or organizational structure.

The table offers an interesting method for evaluating end products, and an opinion about their respective qualities, though some of the values shown are counter intuitive. For example, it isn’t clear why semantically supplemented 2D products represent a greater level of effort than semantically supplemented 3D products. It also isn’t clear why certain end products are necessarily more accurate than others. Accuracy will likely be variable for all of them, and will depend on the underlying technology and methods used to create the visualization.

In considering applicable end products, DoD installations should consider how the project is to be used, who the target audience is, and the nature of the cultural resources that are the subject of the project. Where reaching the widest audience is important, the simplest and easiest to use products should be given a high priority. However, if part of the project aims to provide public access to historic properties where physical access is impractical for practical, security or safety considerations, more immersive, interactive environments may be a good choice in order to increase the quality of virtual access. However, there is a potential trade-off between level of effort and degree of interactivity for both the content creator and the user, summarized in Table 3.2.

Table 3.2: Interactivity versus Level of Effort

Product	Interactivity	Level of Effort
Still Renders	Low	Low
Animated movies	Low	Medium
Digital panoramas	Medium	Medium
3D Viewers	Medium-High	Medium
Interactive Environments	High	High

4.0 Best Practices for Project Design

4.1 Introduction

Designing a visualization project involves combining the technological considerations discussed in Section 2 with potential end products discussed in Section 3. Because DoD cultural resources staff work with historic objects and properties primarily in a compliance framework, the first questions to consider in approaching a potential 3D visualization project naturally concern what purposes (especially regulatory purposes) would the project support, and what consulting parties and stakeholders are involved. Is the primary goal public outreach and interpretation, or is there also an important recordation element? Is a model wanted for condition assessments or building information management? When considering which technologies are appropriate for a given 3D visualization task, it is also important to consider the nature and condition of the subject, and what sources of information are available.

Cultural heritage professionals around the world have been grappling with these and related questions with regard to the 3D visualization of cultural heritage for several years now, and have developed some valuable guidelines in the form of the London Charter for the Computer-Based Visualization of Cultural Heritage. The London Charter for the Computer-Based Visualisation of Cultural Heritage (London Charter) contains important considerations for the design of such projects. The London Charter was conceived in 2006, and came out of a symposium "Making 3D Visual Research Outcomes Transparent" hosted by the Arts and Humanities Research Council (Londoncharter.org 2009). The London Charter Principles are:

> Principle 1- Implementation: The principles of the London Charter are valid wherever computer-based visualisation is applied to the research or dissemination of cultural heritage.
>
> Principle 2 - Aims and Methods: A computer-based visualisation method should normally be used only when it is the most appropriate available method for that purpose.

> Principle 3 - Research Sources: In order to ensure the intellectual integrity of computer-based visualisation methods and outcomes, relevant research sources should be identified and evaluated in a structured and documented way.
>
> Principle 4 – Documentation: Sufficient information should be documented and disseminated to allow computer-based visualisation methods and outcomes to be understood and evaluated in relation to the contexts and purposes for which they are deployed.
>
> Principle 5 – Sustainability: Strategies should be planned and implemented to ensure the long-term sustainability of cultural heritage-related computer-based visualisation outcomes and documentation, in order to avoid loss of this growing part of human intellectual, social, economic and cultural heritage.
>
> Principle 6 – Access: The creation and dissemination of computer-based visualisation should be planned in such a way as to ensure that maximum possible benefits are achieved for the study, understanding, interpretation, preservation and management of cultural heritage.
>
> Denard 2009.

These principles have several important implications for 3D visualization projects carried out for the DoD. Principle 2, for example, suggests that 3D recordation and visualization should not be considered as a sole substitute for the preservation of historic properties, nor should virtual access to historic sites be the sole substitute for allowing physical access to a historic site when it is possible to provide the interested public with physical access. 3D recordation is a valuable tool that can be an important part of an installation's NRHP compliance responsibilities, but should considered together with other available technologies in consultation with the State Historic Preservation Office and other consulting parties and stakeholders.

Principles 3 and 4 relate to conducting and documenting appropriate historical or archaeological research to support a valid 3D interpretation of a historic site. Where laser scanning, photogrammetry, or other 3D recordation of an existing property has been carried out, the methods used should be clearly documented. Virtual reconstructions should be based on the best evidence available, and the nature of the research conducted and evidence found should be clearly documented as part of the project. Where there are gaps in the historical record, or different possible interpretations of the available evidence, this should be made clear in accompanying documentation and, if possible, indicated visually in the resulting products. Because it is possible to produce photorealistic models of past environments, there is a danger of producing a false reality in the mind of an uninformed user. To counter this, it may be possible to layer historical maps or archaeological plan views into a model. It may be desirable to convey doubt about certain elements of a model by rendering those in grayscale rather than color, or partly transparent rather than fully opaque. Alternative interpretations can also be offered where they are consistent with available sources. Such efforts avoid the creation of a false reality while giving a clearer idea of how an understanding of the past is formed.

Principle 5, sustainability, is very important for the future use of 3D visualizations. Thought should be given at the outset of a project to data curation. Where possible, installations engaged in 3D recordation and visualization projects should include specifications in the scope of work that deliverables include open-source file formats where available, and that provisions be made to curate those data. This is especially important where 3D recordation has been used to record existing historic properties. Further considerations and details related to data curation are offered in Section 5.5 of this report.

Principle 6 concerns the creation of digital end products that are usable for the broadest appropriate audience for a visualization project. In assessing the applicability of the digital end products discussed in Section 3, project proponents should consider ease of use and dissemination to appropriate stakeholders. While designing an interactive environment that can be explored on a computer or through virtual reality devices may offer the most immersive and interactive experience, those products may not be as universally accessible as simpler (and less interactive) products such as still renders or animated video files. Laser scanning and photogrammetry have become popular recordation technologies for recording historic sites on DoD installations, but the resulting point clouds may not be as easily shared as other products either because specialized software is required to view the product, or the dataset is so large it is difficult to share, or requires computer resources not available to all users. Thus, it may be desirable in writing a scope of work to include multiple digital deliverables that are accessible to a range of users with potentially limited computer resources.

4.2 Technology Selection and Workflow

Since Principle 2 of the London Charter states that "a computer-based visualisation method should normally be used only when it is the most appropriate available method for that purpose" (Denard 2009), it follows that the technology chosen should be the one best suited to the project goals. The technologies chosen then determine key aspects of the project workflow. Section 1 of this report introduced five broad categories of projects for which DoD installations might employ 3D visualization: recordation/documentation of historic properties; condition analysis and asset management; assessing effects under NHPA; historical research and analysis; and public interpretation. Each of these project types may warrant particular considerations in choosing the most applicable technology. Some questions to consider include:

- What are the cultural resources management purposes of the project?
- Is the recordation of existing resources involved?
- Is the recreation of missing features desired?
- Should the visualization recreate the property at different points in time, or with alternative interpretations?
- What functions does the visualization need to support (e.g. engineering applications, visual effects determination, public interpretation)?
- What level of user interactivity is desired?
- How will the end materials be distributed?
- How will the end materials be curated?
- What is the available level of effort?

4.2.1 Recordation and Documentation

If the project involves recording an existing historic property, then optical technologies like laser scanning or photogrammetry may be appropriate. In the case of an existing building, laser recordation or photogrammetry are popular choices. The precision and accuracy of these methods may be valuable if condition assessment is needed, such as determining whether walls are shifting or deforming in some way. In this case, either photogrammetry or laser recordation may be appropriate. Depending on the camera and distance to the subject, photogrammetry can be as or even more accurate than a laser scanner. But if it is important to document accuracy, it may be easier to do this with a laser instrument. Determining accuracy for photogrammetry may involve calculations involving resolution, exposure, focus, depth of field, distance to the subject, and number of images taken. If lighting challenges are an issue, or if the subject is partly obscured by vegetation, laser scanning may also be a better choice.

Either photogrammetry or laser recordation will work for recording archaeological sites or landscapes. Again, in cases where the historic property is partly obscured by dense vegetation, laser scanning is likely to yield better results. On the other hand, as a matter of practicality and convenience, digital cameras are standard equipment for archaeological field teams, and a small archaeological feature can be recorded very quickly at very low cost by the field team that excavated it, without resort to complex and expensive laser instruments. Indeed, recording a feature in the field through photogrammetry can be completed within a few minutes, making this a good supplement for traditional measured drawings that capture the associated semantic information about soil textures and observed stratigraphy (Figure 4.1). In the case of small objects such as artifacts, laser scanning and photogrammetry may also be useful, but there may be instances where other technologies such as RTI or Structured Light Recordation (discussed in Section 2.1.3) may be useful. RTI for example, allows subtle variation on a flat surface to be enhanced, potentially valuable in the analysis of faded engravings, for example.

Figure 4.1: Photogrammetric recordation of brick foundation feature, Joint Base Charleston, SC. Click to activate 3D content in pdf version.

The long-term sustainability of project end products should be considered carefully if digital recordation is planned for historic properties, especially those planned for demolition, or at risk for loss. This can be a significant challenge since there is a wide variety of software applications that generate 3D models, and a wide variety of proprietary file formats; moreover software continues to evolve, meaning that new formats are likely to be created. In general, provisions should be made to curate digital products in their original, native format. Where those products are proprietary software files, consideration should be given to also exporting the resulting model to open-source or widely used formats where available (e.g. obj, ply, or fbx formats for 3D meshes). Orthographic and perspective renders of the model from various views might also be printed out, and those physical prints curated; 3D printing may also be an option in some cases. It should be noted that files produced by laser scanning or photogrammetry can be quite large. This can present storage and associated cost issues for proper data curation that should be considered when the technology and end products are selected for the project. Section 4.5 below provides a discussion of data curation.

4.2.2 Condition Analysis and Building Management

As discussed above in Section 4.2.1, laser scanning or photogrammetry can be effective tools for accurately recording a building's current condition. Subsequent scans can then be made that will allow engineers to assess whether the building is being deformed in some way. If in addition to assessing condition, asset management tools are desired it is important to note that significant effort may be needed to modify models created by laser recordation or photogrammetry for use in a BIM. There are few automated tools to support this, and the person entering building elements into the BIM may have to more or less trace from the scanned model in a 3D CAD environment. In cases where there are reliable as-built drawings, it may be simpler and more cost effective to create the BIM from the drawings, rather than incur the expense of laser scanning or photogrammetry if the accuracy and precision of those data are not required.

4.2.3 Assessing Effects

Evaluating and communicating the potential visual effects of an undertaking on a historic property can be greatly facilitated by 3D visualization. Elements of the model or models that do not yet exist will need to be created one or another of the many 3D CAD applications. However, extant resources in the model can be recorded in a number of ways, including through optical means (lasers or photogrammetry), or by CAD modeling, from as-built drawings, photographs, or other sources. Which is the most appropriate depends on what other purposes those data will be used to support. If precise and accurate recordation is needed to support condition assessment or other detailed recordation needs, then optical recordation through laser scanning or photogrammetry may be appropriate. However, if the assessment and communication of visual effects is all that is needed, it may be more cost-effective and expedient to model the existing resources in a 3D CAD program only to the level of detail needed to support the analysis. Geographic information is likely to be important in analyzing visual effects. Digital models of existing resources and planned changes may need to be combined with GIS data. Where GIS data are a critical component of the analysis, developing models with applications such as ESRI's City Engine or Google Sketchup may be alternatives worth considering.

4.2.4 Research and Analysis

All of the visualization technologies discussed in this report have potential applications in the analysis of historic properties. Which is the most appropriate depends on the nature of the resources involved and the analysis planned. In general, the technology selected should support the level of detail needed. Opting for a greater level of detail than is needed to support the analysis may introduce unnecessary costs and complications in data manipulation, curation and dissemination. For example, if analysis is aimed at exploring the relationship between extant and non-extant resources, modeling of the non-extant resources must be done with CAD software. It may be easier to model extant resources with the same software used to model the recreated elements than to use optical recordation methods, and then import those results into the CAD software if the added detail of the optical recordation is not needed.

4.2.5 Interpretation

The issues concerning the best technologies to use for interpretation in many respects mirror the issues for research and analysis, except that additional consideration may be warranted with regard to end products. As with research and analysis, the technology selected should support the level of detail needed. Again, opting for a greater level of detail than is needed to support the analysis may introduce unnecessary complications. But if the focus of the project is to produce materials for dissemination to the interested public, then the project should be designed from the beginning to support end products that will be usable by the target audience. In this case, optical recordation methods that produce dense point clouds may present challenges for distribution. Point clouds won't be supported by software most users will have installed on their computers. Meshes exported to 3D pdf file format can be opened by the Adobe Viewer, but if the model is very large, performance on many viewers' machines may be poor unless the resolution of the model is reduced first (decimated). Reducing the polygon count of a hi-resolution mesh while retaining high resolution for the associated texture file can produce a product that visually conveys the detail of the object while being less demanding of a user's computer resources. Point Clouds and dense meshes can also be made available online for viewing through a web browser, or distributed together with free viewer software, but this may require the user to install software on their machine, and it may also may require that steps be taken to reduce the overall size of the complexity of the point cloud or mesh to allow for acceptable performance. Where public outreach is a primary focus of the project, producing interactive media can allow for deeper audience engagement, but it may be worthwhile to consider products simpler to use, such as static renders or movie files, in addition to interactive media in order to avoid erecting technical barriers for some users.

The kinds of end products envisioned for a public outreach project may influence the 3D modeling workflow. It may not be necessary to model more than what is needed to support the end result. If still images are planned, then it may be most efficient to only model what will actually be seen. Where an interactive environment is planned, it will be necessary to model anything that the user may be able to see in exploring the environment. In this case, the model may need to be more complete than for a project involving only renders from particular camera angles. It may also be necessary to model as efficiently as possible from a geometry perspective in order to produce 3D assets that will not slow computer performance unnecessarily. Where fixed renders are planned, that may not be an important constraint. Similarly, the file format of anticipated deliverables may necessitate data conversions that may be problematic for certain kinds of approaches. For example, some elaborate lighting schemes or complex material shading networks possible in Maya, and suitable for still or movie renders, may present a challenge when an interactive deliverable such as a 3D pdf or an interactive environment is planned.

4.3 Research and Documentation

London Charter Principles 3 and 4 concern conducting research adequate for the visualization, then documenting the results of that research. Conducting research to support interpretation of historic sites, as well as methods for documenting that research, are well understood within cultural resources management. In addition to that sort of documentation, 3D visualization projects should produce documentation that describes what the goals of the visualization were, and clearly documents the technical methods used. If the project includes recordation of extant features, the documentation should include the time, date and place of recordation; what instrument was used, and how the data were subsequently modified. A project that includes virtual reconstruction of historical elements that are no longer extant should clearly document what has been reconstructed, along with information about the reliability of the visualization.

In addition to verbally describing methods used, results, and how those results support site interpretation, it is important that the results of the research, as well as the limitations of that research, be portrayed visually as a part of the end products produced. There are many ways in which this may be done. Where the research supports multiple interpretations, it may be necessary to construct more than one version of the model. Where there is better evidence or more confidence for some portions of the visualization than others, it may be good practice to visually convey uncertainty, such as by different coloring or opacity. Where animation is planned, differing interpretations or levels of confidence can be shown dynamically; for example, all elements might initially be shown in the same way, but then areas of uncertainty could change in color, opacity, or some other characteristic. There may also be opportunities to layer in explicit references to available data, such as projecting archaeological maps or planviews on landforms (as in Figure X in Section 3.2).

Where optical technologies such as laser scanning or photogrammetry have been used to document a historic property as part of HABS/HAER recordation, additional documentation may be needed to capture certain physical details and their associated semantic information. There has been a significant amount of work concerning how to generate 2D orthographic drawings from 3D meshes. These typically involve devising algorithms to identify edges by finding abrupt changes in the angles of faces in a mesh. Examples include Kim et al. 2010; Murphey et al. 2009; and Miranda et al. 2008. In 2014, the UK software firm Arithmetica began distributing software that makes this process relatively automated (http://pointfuse.com/). The NPS Heritage Documentation Program also has some guidance on using laser recordation for HABS/HAER/HALS recordation: (Lavoie and Lockett nd). While 3D models provide exceptional value in the recordation of a historic building or structure, they do not necessarily capture everything of interest for historic preservation. Layers of paint may obscure edges or joins important to capture and interpret, for example (McNatt 2012). A 3D model should not be regarded as sufficient in itself, and may sometimes be better as a supplement to the semantic information captured in traditional means of recordation.

4.4 Access

Many 3D applications produce very large datasets in a proprietary format that may require uncommon, expensive software to view or edit. Consideration should be given to producing file products that can be viewed by low-cost or open-source software. Final products should also include files that can be broadly disseminated, such as still renders, movie files in multiple common formats, and possibly interactive html formats. Where distribution of interactive media is desired, it may be necessary to include needed software (as licensing permits), along with detailed, but easy to follow, user instructions.

4.5 Sustainability (Archiving)

In order to prevent the loss of valuable digital data over time, consideration should be given to storing the digital end products for long-term archiving. This is especially important for projects installations carry out in compliance with the NHPA, and where the data logically fall under the requirements of 36 CFR 79, Curation of Federally-Owned and Administered Archaeological Collections. One alternative is to make use of an existing digital data repository, such as the Digital Archaeological Record (tDAR). Digital Antiquity, a non-profit organization at Arizona State University, hosts tDAR. tDAR is prepared to curate data from 3D visualization projects, and has a number of 3D scans in its inventory. These include various data types, though they are mostly obj files. Project documentation stored with the data should include relevant metadata so that the data will be discoverable and usable for future generations. Digital Antiquity has prepared some guidelines for curating 3D objects following best practices developed by Britain's Archaeological Data Service (Brin 2014; Barnes nd). These best practices offer guidelines for preparing metadata for photogrammetry that would be applicable to other 3D visualization projects as well.

When preparing data for curation it is important to consider the nature and limitations of file formats when considering how the data should be archived. Project electronic files should be archived, if possible, in their native format at a repository that has the ability to maintain the software needed to open the file, and migrate the files to new versions as necessary, or that will be able to maintain legacy hardware and operating systems needed to run the applicable software. Being able to preserve the data in their original format is particularly important for datasets such as lidar or photogrammetry that record extant features. The use of open-source data formats may greatly facilitate data archiving. Metadata concerning the instrument used and its position and distance from the subject should be maintained for laser recordation projects. Likewise, photogrammetry projects should archive the original photographs and associated metadata, as well as the resulting point clouds and meshes. Overall project documentation should also be preserved.

There are a large number of file formats in use in 3D CAD modeling and animation. McHenry and Bajcsy (2008) provide an analysis of some of the most popular formats. They point out that 3D scenes include a number of components that should be considered when archiving projects: geometry, appearance (i.e. color, material, and physical texture applied to the geometry), and scene elements (such as lighting, virtual cameras, and animation). They suggest that for preservation purposes, geometry is the most important to preserve, followed by appearance and then other scene elements like lighting and animation. They provide an analysis of popular file formats, and what information they can hold. In considering these parameters, there are trade-offs to be aware of. Highly portable formats, like Wavefront obj files, do a good job of preserving geometry and appearance, but don't store information about scene elements like lighting or animation. The format is very simple, an obj file can be opened in a text editor, and the information readily understandable as a series of x, y, z coordinates in plain text. This makes obj files a good choice or archiving objects, but not a good choice for archiving a whole scene used to create an animated sequence. The Standford polygon file format (ply) is another open-source file format for 3D objects. Like obj, it stores geometry and appearance data, but it is extensible to allow additional attributes to be stored through future development. However, like the obj format, it cannot store animation or elaborate scene information.

Formats that hold a wide range of scene elements tend to be more proprietary in nature. This makes intuitive sense since the more elaborate the scene, the more the file that holds that information will depend on specific features of the software that produced it. But even here, there are some formats that allow for a degree of portability. The Filmbox (fbx) format for example, owned now by Autodesk, is a good choice for portability among the wide range of popular modeling and animation software owned by Autodesk, such as Maya and 3dsMax. Where project deliverables include complex scenes, consideration should be given to archiving in the original format, to preserve all of the features, as well as additional formats that will preserve key attributes in a form readable by a wider range of applications.

The situation is somewhat different for data types used in laser scanning and photogrammetry. While the software applications that process lidar and photogrammetry data use proprietary file formats, there have been some efforts to produce open source file standards specifically for 3D point cloud data. The American Society for Photogrammetry and Remote Sensing have produced the LASer (LAS) file format (ASPRS 2012). Similarly, the American Society for Testing and Materials (ASTM), an international standards organization, has developed the E57 file standard for the exchange of 3D data files. The E57 file format is documented in the ASTM E2807 standard (E57.04 3D Imaging System File Format Committee 2012). Use of these formats can help make objects recorded by lasers or photogrammetry more accessible, as can generating a mesh from the point cloud, and saving the resulting product in a portable format such as obj or ply.

5.0 PROTOCOLS

This section is intended to provide a synthesis of what DoD installations should consider when designing a 3D visualization project in support of cultural resources management goals. Overall, the key best practices are to have a clear goal in mind, and choose the right technology and end products to support that goal. The project should produce clear documentation that outlines the goals and the full workflow so that someone else could replicate the project. The data should be provided in formats that are accessible with open-source software where possible and with long-term curation in mind.

5.1 Define Project Goals

Any cultural resources project initiated by a DoD installation as part of its obligations under the NHPA, or other cultural resources related authorities, should involve consultation with relevant stakeholders. If the project includes recording a historic property, the State Historic Preservation Officer (SHPO) and possibly the NPS, should be involved. If the project is planned as part of an alternative mitigation pursuant to a Memorandum of Agreement (MOA), the plans will need to be discussed with the consulting parties stipulated in the MOA.

Best Practices

- Consult as early as possible. Include the public and other interested parties such as associated descendants or veterans groups.
- Consider the nature of subject resource (condition, location, future plans).
- Evaluate the project goals and methods according to the London Charter for the Visualization of Cultural Heritage.

5.2 Define End Products

Once the overall goals for a visualization project are identified in consultation with relevant stakeholders, the range of end products can be specified.

Best Practices

- Consider a balance between level of effort, accuracy, ease-of-use, and degree of interactivity.
- Determine from stakeholders the range of potential uses for current or follow-on projects such as HABS/HAER recordation, effects determination, asset management, or public outreach.

5.3 Choose Technology

What technologies will be needed to create the visualization should follow from defining what the specific end products will include.

Best Practices

- The technologies employed (optical recordation techniques or CAD modeling for example) should produce accuracy needed to support defined project goals, but it may not be good practice to exceed those needs.

5.4 Document

The project should clearly document the project goals, consultation involved, technologies chosen, and methods employed. The results of associated historical or archaeological research should be discussed.

Best Practices

- The technology employed for recordation, and steps taken in data processing should be documented.
- The sources used and potential uncertainty in virtual reconstructions should be incorporated into the visualizations themselves as well as described in accompanying text.

5.5 Curate

Providing for curation for digital products associated with archaeological projects on federal land is a requirement of 36 CFR 79. Even when archaeological sites or projects are not involved, data curation should be considered an important best practice in order to avoid potential loss of valuable cultural resources program investments.

Best Practices

- Consider including open-source or highly portable file formats in deliverables.
- Visualization technology is a rapidly evolving field; installations may wish to avoid rigid file specifications in a scope of work, asking that vendors instead specify in their technical approach how they will address issues of future access.

6.0 Example Projects

6.1 Building 8 Interiors, Marine Corps Barracks, Washington

One of the two demonstration projects focused on the interior for Marine Corps Barracks Washington Building 8. Building 8 was built in 1902 as bachelor enlisted quarters. While the exterior retains a high degree of integrity, parts of the interior of the building have changed dramatically, and it is often difficult for a visitor to get a sense of how the interior space was originally configured. For example, part of the second floor now used for a locker room is shown in a World War I era photograph as a long open hall filled with low metal bunks. The contrast between its historical appearance (Figure 6.1) and current use (Figure 6.2), together with the historical photograph to provide a basis for interpretation, made this a logical choice for creating a virtual interior space.

Data sources used to construct the second floor interior included a Revit model of the current building conditions, floor plans (Figure 6.3), and the 1917 photograph (Figure 6.1). Sources for the stair details included drawings of the railing (Figure 6.4; Michael Baker Jr., Inc. 2012), and photographs Versar took of current conditions (Figure 6.5). The current Revit model was imported into Autodesk Maya, and the second floor room edited to reflect conditions shown in the 1917 photograph. The model was rendered with the Mentalray render engine, using the Physical Sun and Sky lighting solution (Figure 6.6). In addition to this still render, an interactive 360 degree render was prepared that can be viewed from a web browser, thus expanding the view beyond what is shown in the 1917 photograph.

Figure 6.1: Squad room 1917. (Baker 2012).

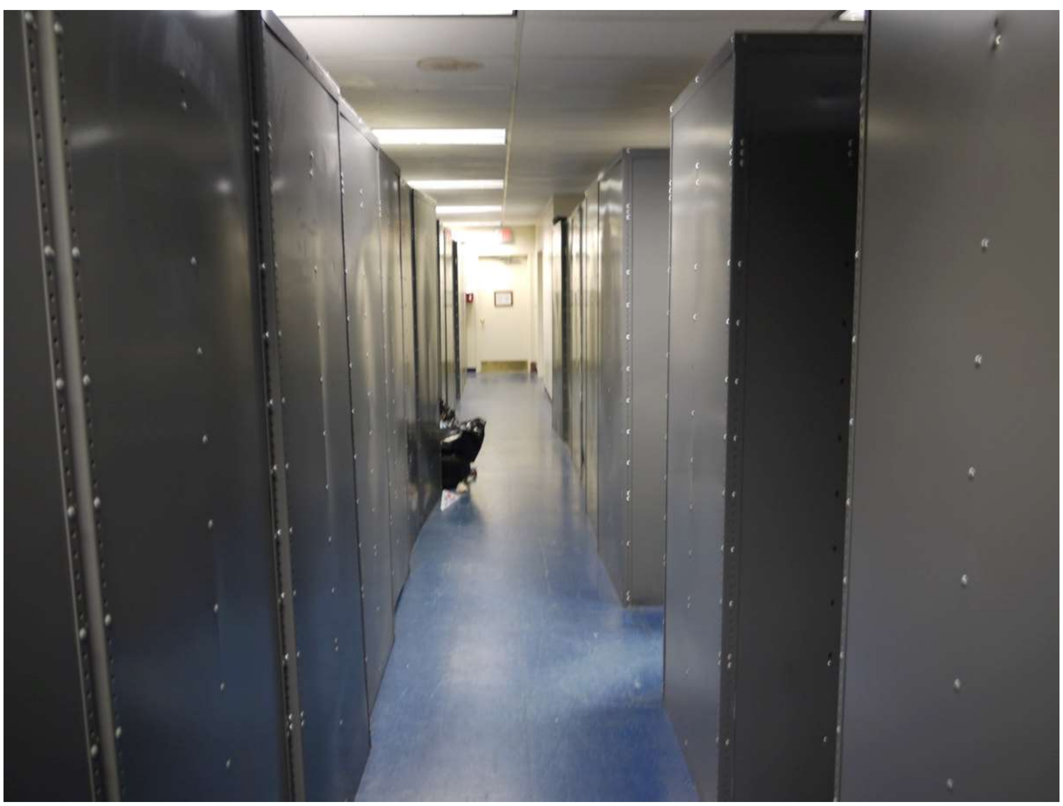

Figure 6.2: Current appearance, Building 8 second floor.

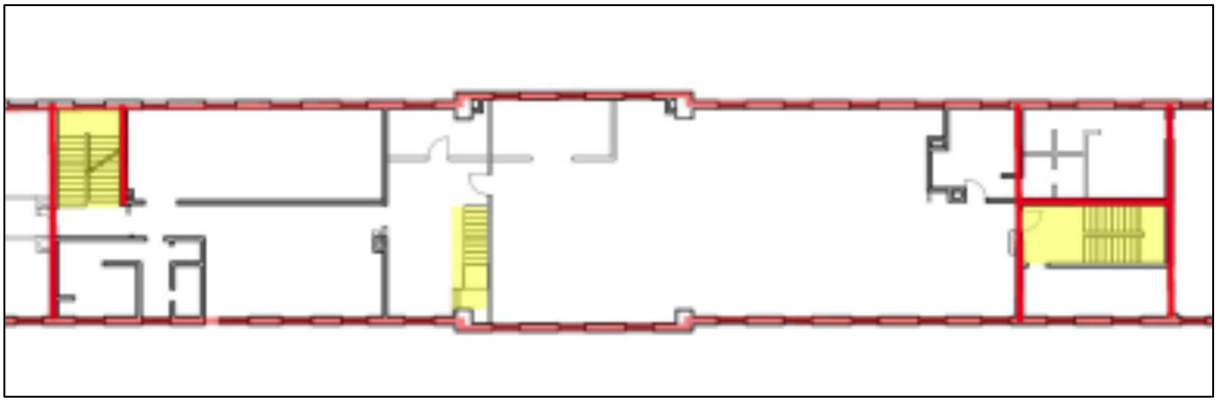

Figure 6.3: Current configuration of Building 8 second floor (area shown in Figure 6.2).

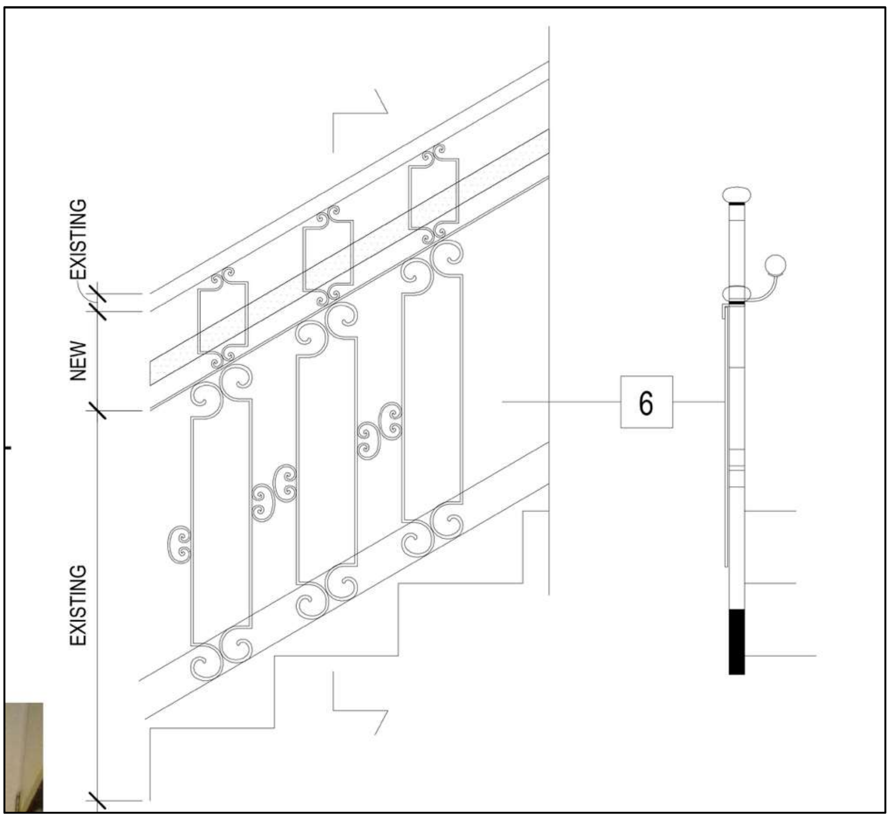

Figure 6.4: Building 8 stairway railing profiles

Figure 6.5: Building 8 second floor staircase.

In the process of creating the interior model of the second floor of Building 8, it became apparent that the wall with double door visible at the far end of the hall in the 1917 photograph is no longer present. Counting the windows from the open staircase, the location of this missing wall can be shown in the planview in Figure 6.7. Modeling and positioning beds in the room (assuming the beds were 3-feet wide), suggests that the room may have slept approximately 70-75 men at the time the photograph was taken (6.8).

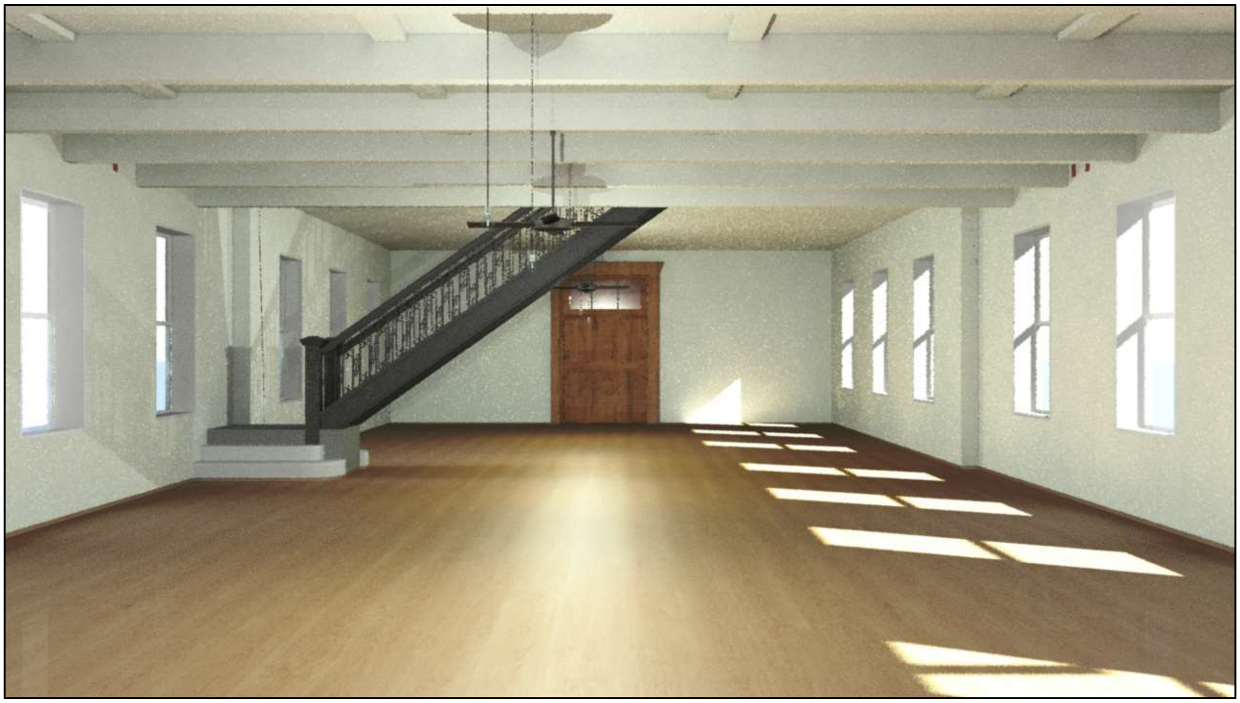

Figure 6.6: Still render, reconstructed Building 8 second floor interior.

Figure 6.7: Difference in second floor plan view from conditions in 2015 (above) and 1917 (below).

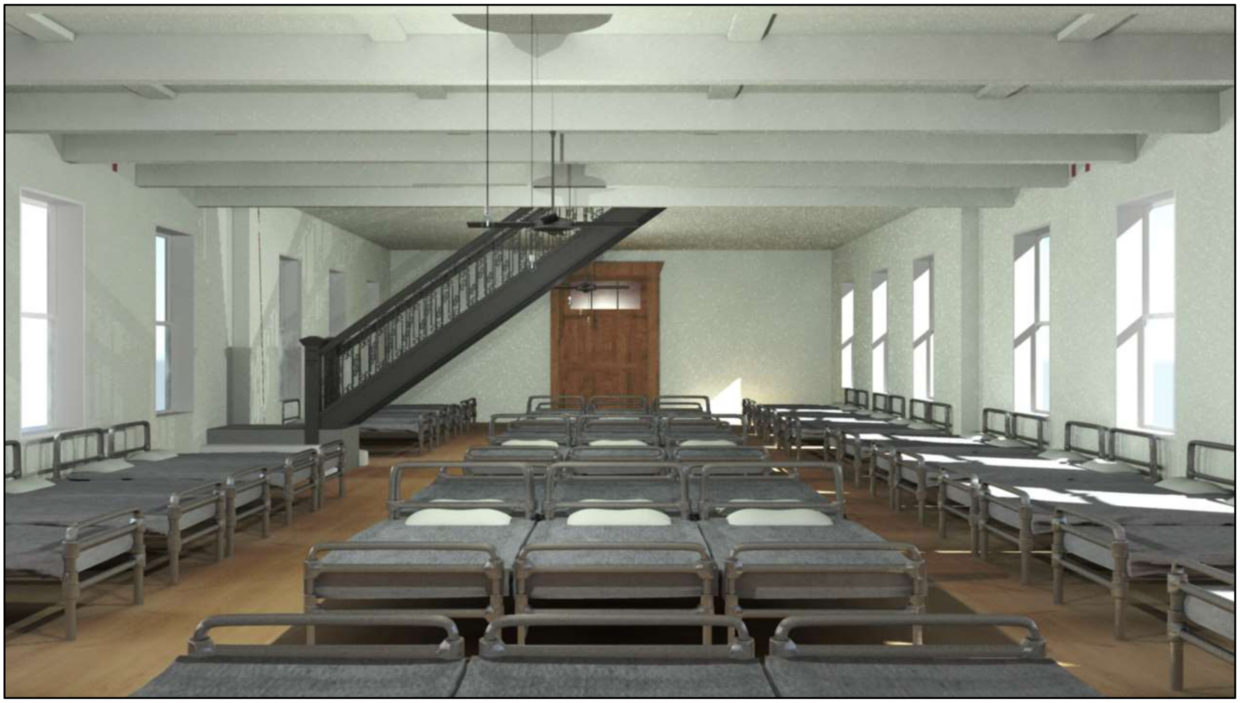

Figure 6.8: Still render, reconstructed Building 8 second floor interior with beds.

Original interior elements in Building 8 are relatively scarce. As an aide to documenting some of these, photogrammetry was conducted on each of the surviving original fireplaces (Figures 6.9, 6.10, and 6.11). A series of overlapping digital photographs was taken of each fireplace, and then imported into Agisoft Photoscan. These 3D models have been converted into 3D pdf files, and are shown below. Click to activate 3D content in pdf version of this report.

Figure 6.9: 3D pdf of Protocol Office Fireplace.

Figure 6.10: 3D pdf of Command Sargent Major Office Fireplace.

Figure 6.11: 3D pdf of Commanding Officer's Fireplace.

6.2 16th Century Spanish Santa Elena, MCRD Parris Island, SC

The archaeological site of Santa Elena on Marine Corps Recruit Depot (MCRD) Parris Island includes the archaeological remains of the sixteenth-century capital of Spanish Florida (Figure 6.12). The site was initially excavated in 1923. Based on those excavations, physical interpretive signs were installed. Subsequently, the University of South Carolina began a long-term program of archaeological excavation on the site. In an ongoing program carried out since 1979, this program has identified the remains of Fort San Felipe, possible remains from the village of Santa Elena, and possible remains of the 1562-63 French fort of Charlesforte. The most intensive excavations have been carried out in the area of Spanish Fort San Felipe, including the northwest bastion, and a portion of the fort center (South 1996; DePratter 2005).

Fort San Felipe was begun after the Spanish took control of the location from the French in 1566. The fort appears to have burned in 1570, after which it was rebuilt. The Spanish then built a new fort, San Marcos, to the south of San Felipe. Fort San Felipe was subsequently abandoned and taken down in about 1574 or 1575 because it had been built without authorization. In 1576 the settlement of Santa Elena was attacked and destroyed by Native Americans. The Spanish rebuilt Fort San Marcos, but ultimately abandoned Santa Elena in 1587 in favor of Saint Augustine in Florida. The models developed for this project focus on Fort San Felipe as it may have appeared circa 1572.

Figure 6.12: Archaeological planview of Santa Elena (South 1996) superimposed on an aerial photograph of MCRD Parris Island, SC.

The available data on which to base the Santa Elena virtual reconstruction includes the current USGS Digital Elevation Model, documentary research summarized in archaeological reports prepared by the University of South Carolina along with archaeological plans and descriptions of materials found on the site. Key gaps include portions of the landform that have eroded substantially since the 16th century. The archaeology carried out thus far gives an indication of settlement footprint, but little information is available about what the buildings looked like, and the relationship of identified features to individual buildings is uncertain. This makes a representation of the village conjectural. Buildings in the settlement were likely earthfast, wattle and daub construction. Evidence for these in the archaeology can be ephemeral, so the layout of the town itself is likely incomplete.

Work on the 3D model for Santa Elena began with a review of the published archaeological reports available. These were available online from the University of South Carolina Scholar Commons. GIS software was used to georeference the published site plans to real world coordinates with the help of aerial photographs. A model of the current ground surface was created based on the USGS Digital Elevation Model. This ground surface was then modified following the estimated sixteenth-century shoreline depicted in the archaeological reports (South 1985; Figure 6.13). The fort model was then built extrapolating from the archaeological features supplemented by information about 16th-century fortification practices. The model was developed in Autodesk Maya and rendered with the Mentalray render engine, using the Physical Sun and Sky lighting solution.

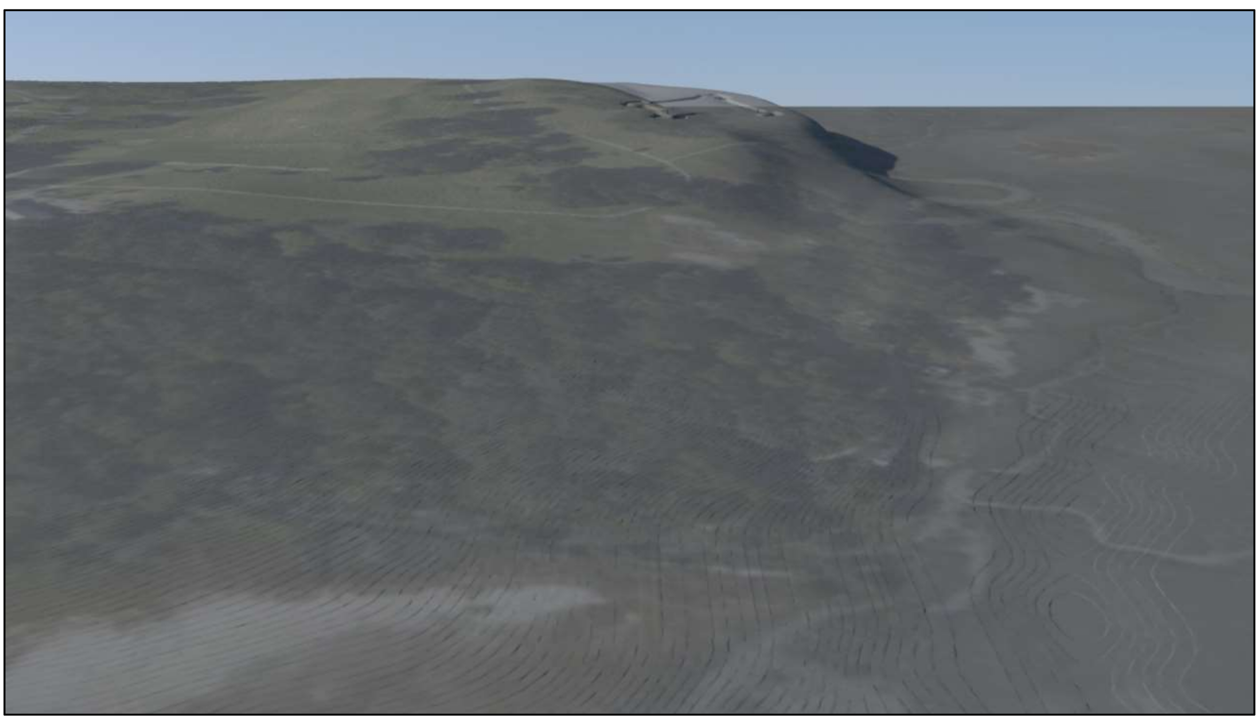

Figure 6.13: Conjectural 16th-century shoreline (very low relief exaggerated for this illustration).

This exercise prompted questions about how to interpret the archaeological plans. For example, how did the palisade ditch surrounding Fort San Felipe articulate with the bastions? Figure 2 from “Excavation of the Casa Fuerte and Wells at Ft. San Felipe 1984” (South 1985) seems to suggest that the NW Bastion and the palisade ditch were separate, though the dashed lines for the palisade ditch could mean that no evidence for it was found between the Casa Fuerte and the NW Bastion. One possibility was that the NW Bastion was completely separate from the palisade, or, more likely, the palisade met up with the bastion walls. Figures 6.14-15 show some renderings of different versions of the model that illustrate this question.

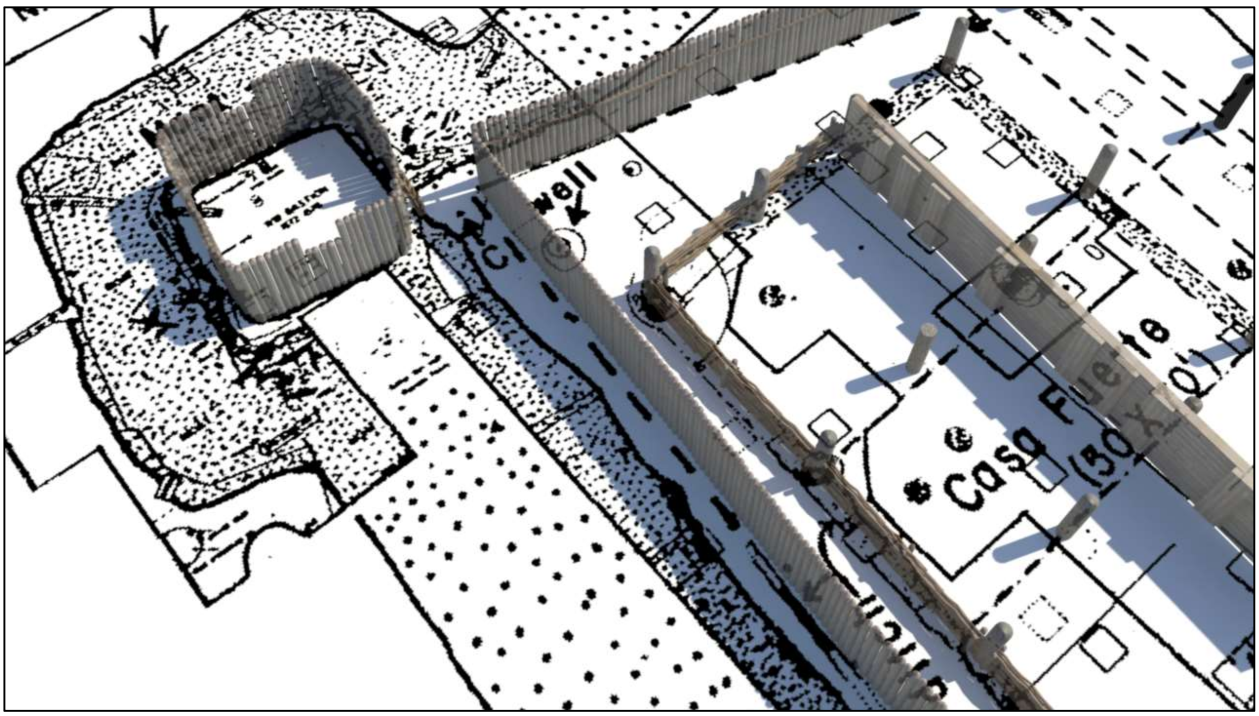

Figure 6.14: Reconstructed palisade superimposed on Ft. San Felipe Interpretive Plan (South 1985).

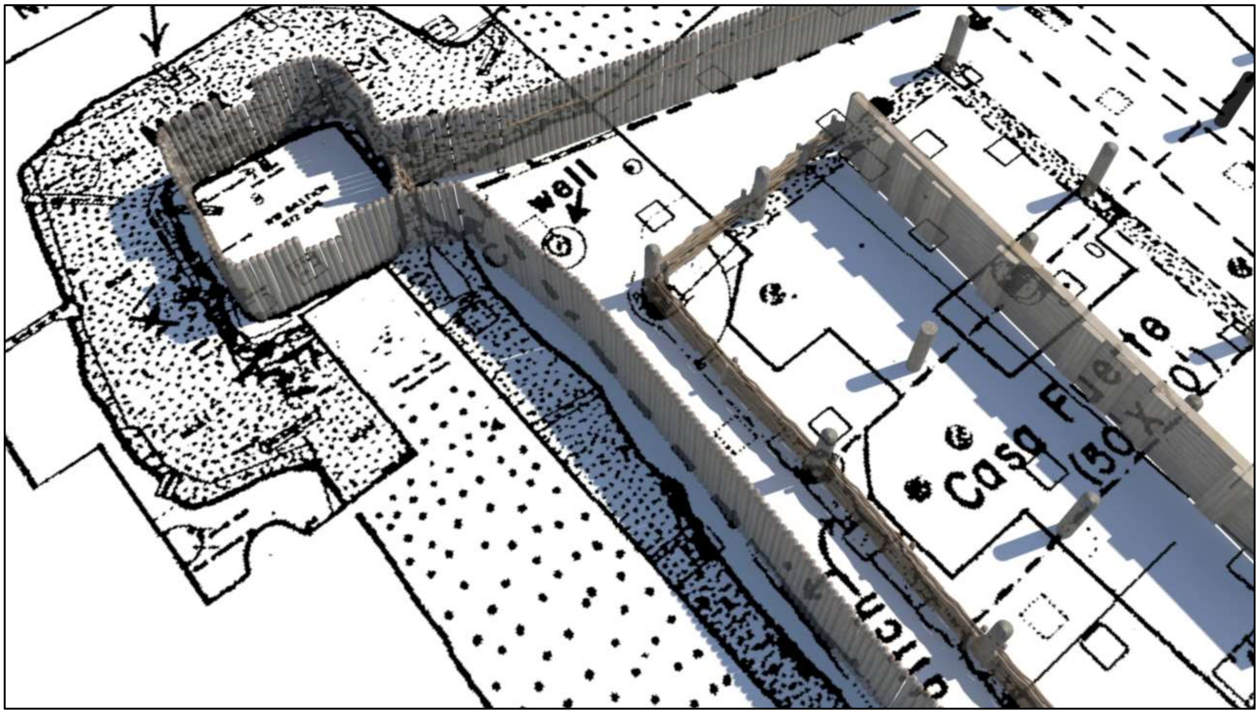

Figure 6.15: Reconstructed palisade superimposed on Ft. San Felipe Interpretive Plan (South 1985) showing hypothetical integration of NW bastion with the main palisade.

Another interpretive question concerned how was dirt piled behind the palisade. The palisade shown in Figure 6.16 follows the palisade ditch feature indicated in South's figure. This imagines a 10 ft high palisade, and a ladder to allow access. The historical images of Fort San Marcos (a later fort at Santa Elena) show ladders at the bastions. Several different ways in which dirt might have been piled behind the palisade to make a platform were modeled. The first attempt followed the example of a corner bastion shown in South (1996). Figures 6.17 and 6.18 show this, but this seems to leave little room to mount artillery. Figures 6.17-21 show an approximately 6 foot long artillery piece mounted on a carriage similar to those found on ships. Mounting the cannon on the sorts of carriages designed to be pulled by horse would seem to make the problem of room worse. This also raises the question of how well the palisade would have been able to support the weight of sand piled that high.

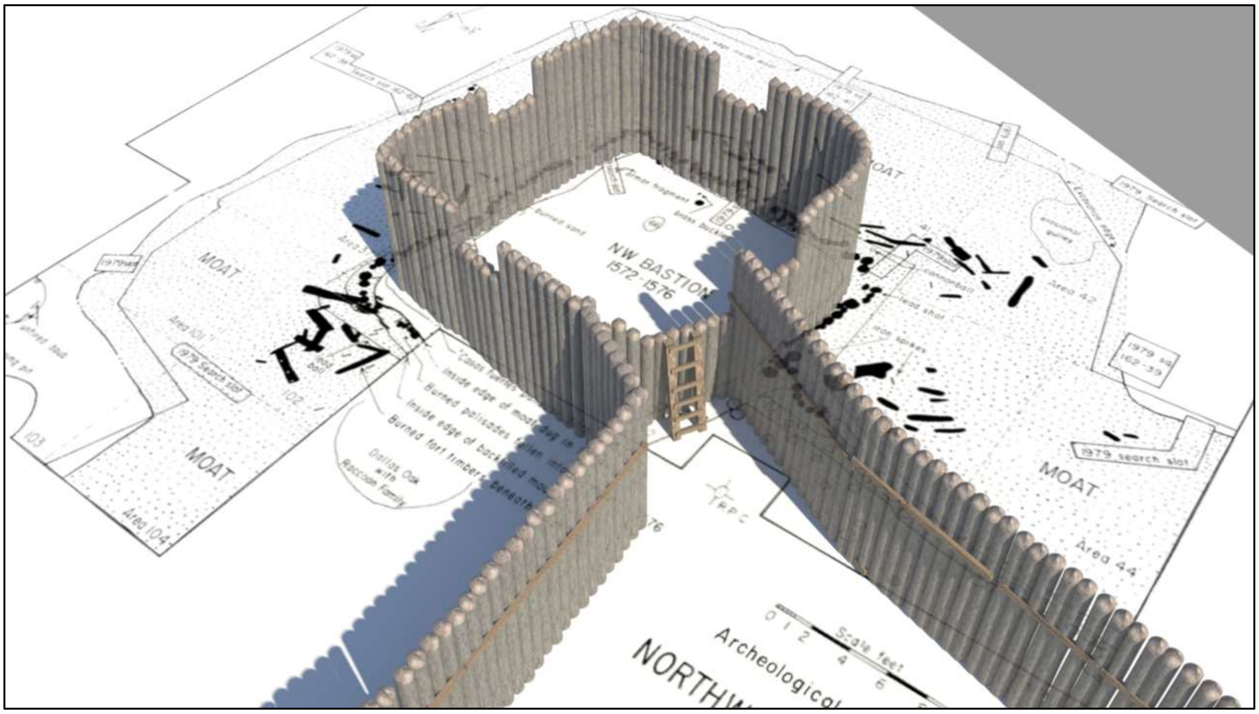

Figure 6.16: Northwest bastion palisade superimposed on Figure 15 (South 1985).

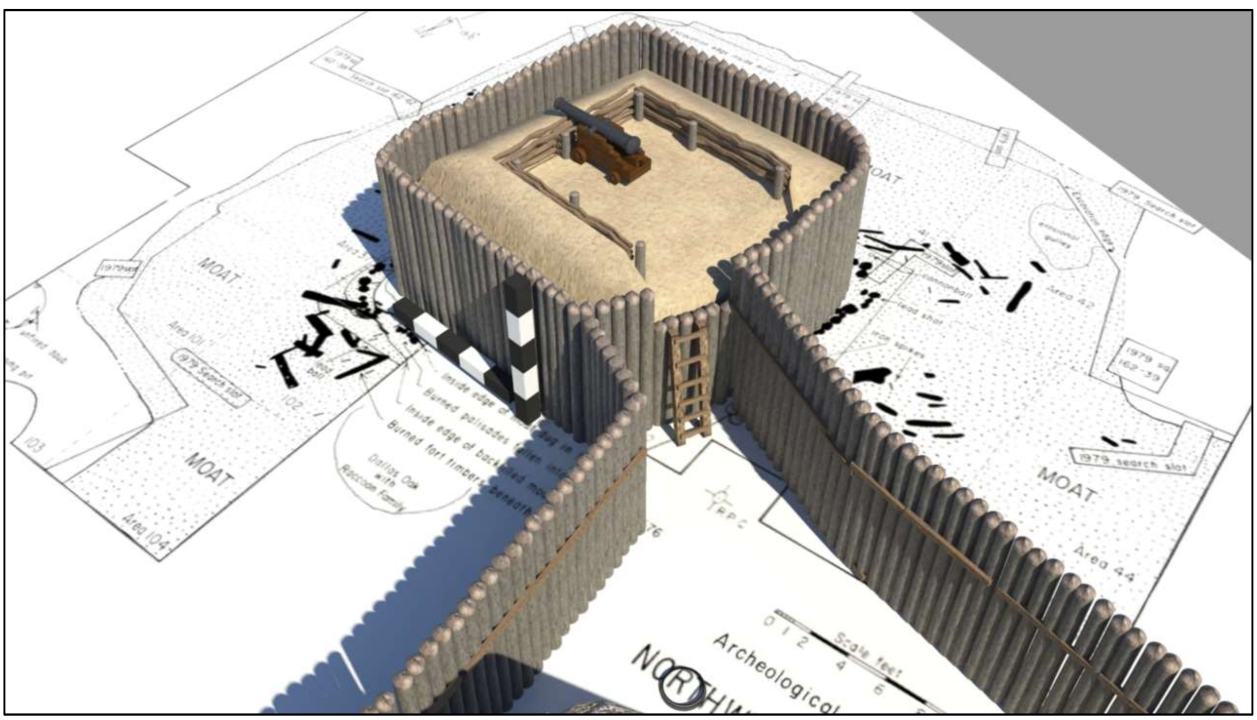

Figure 6.17: Bastion sloped behind palisade, with 6ft-long falcon artillery piece.

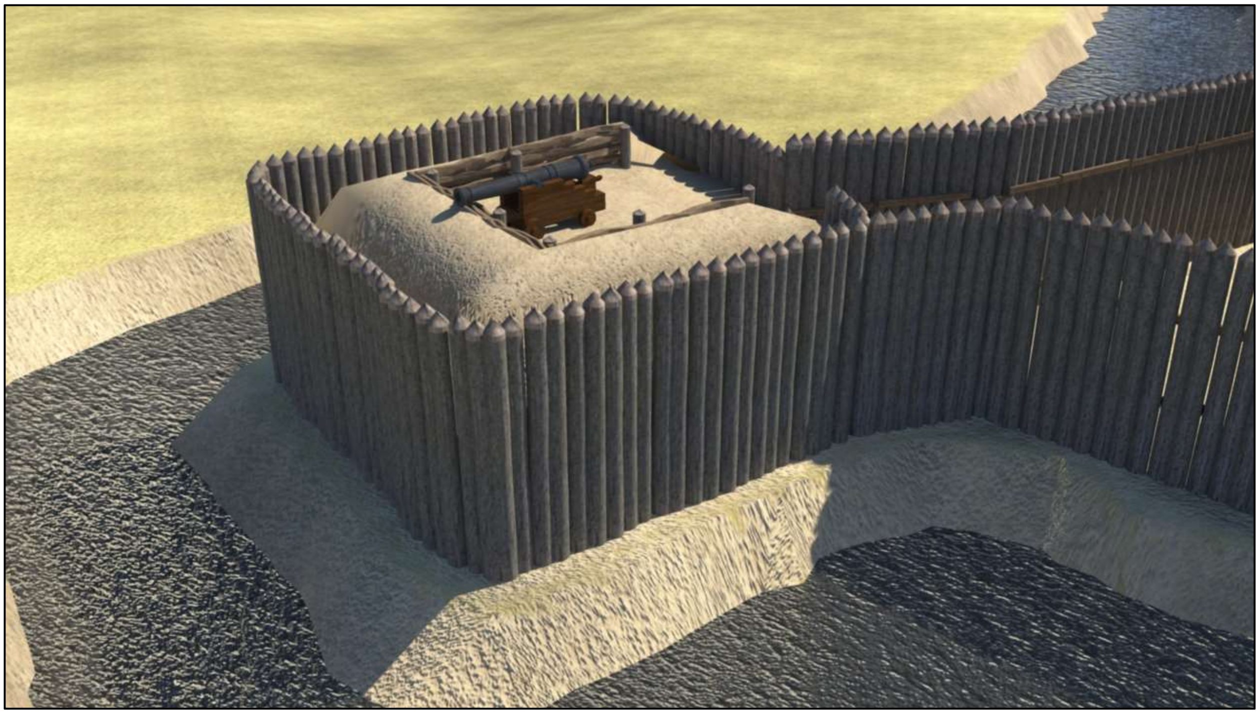

Figure 6.18: Bastion sloped behind palisade, with 6ft-long falcon artillery piece.

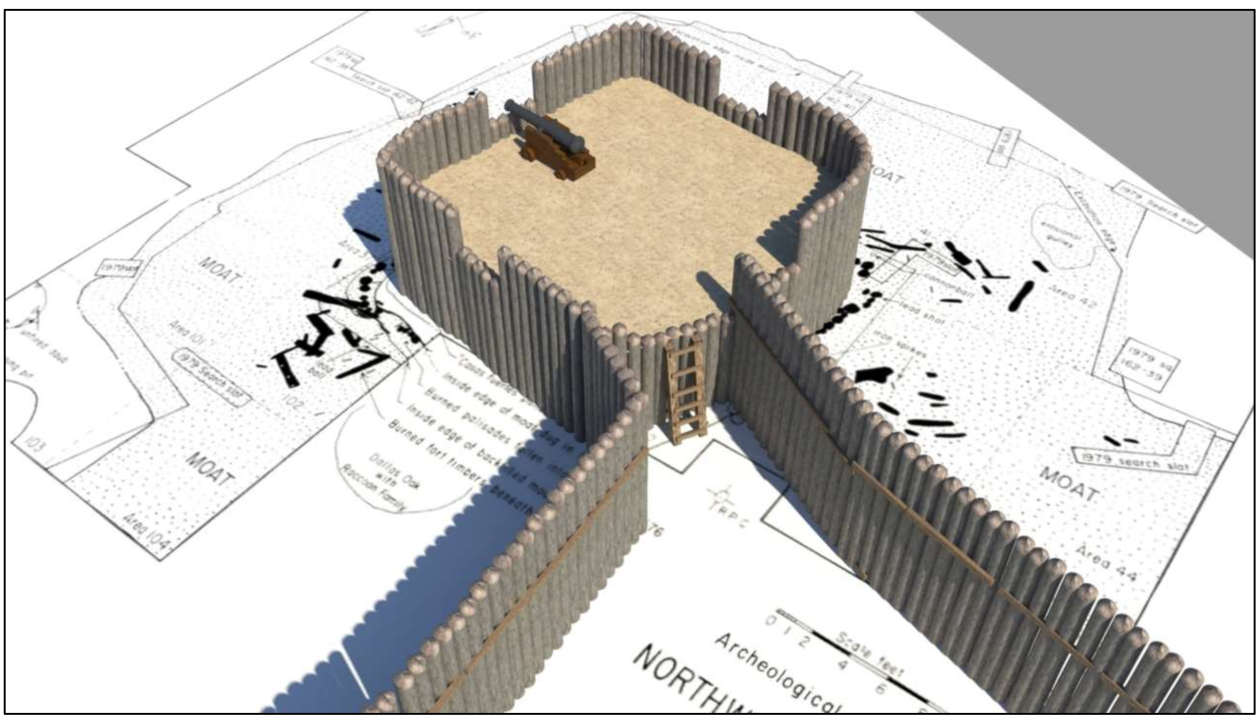

Figure 6.19: Simplified bastion with ladder access.

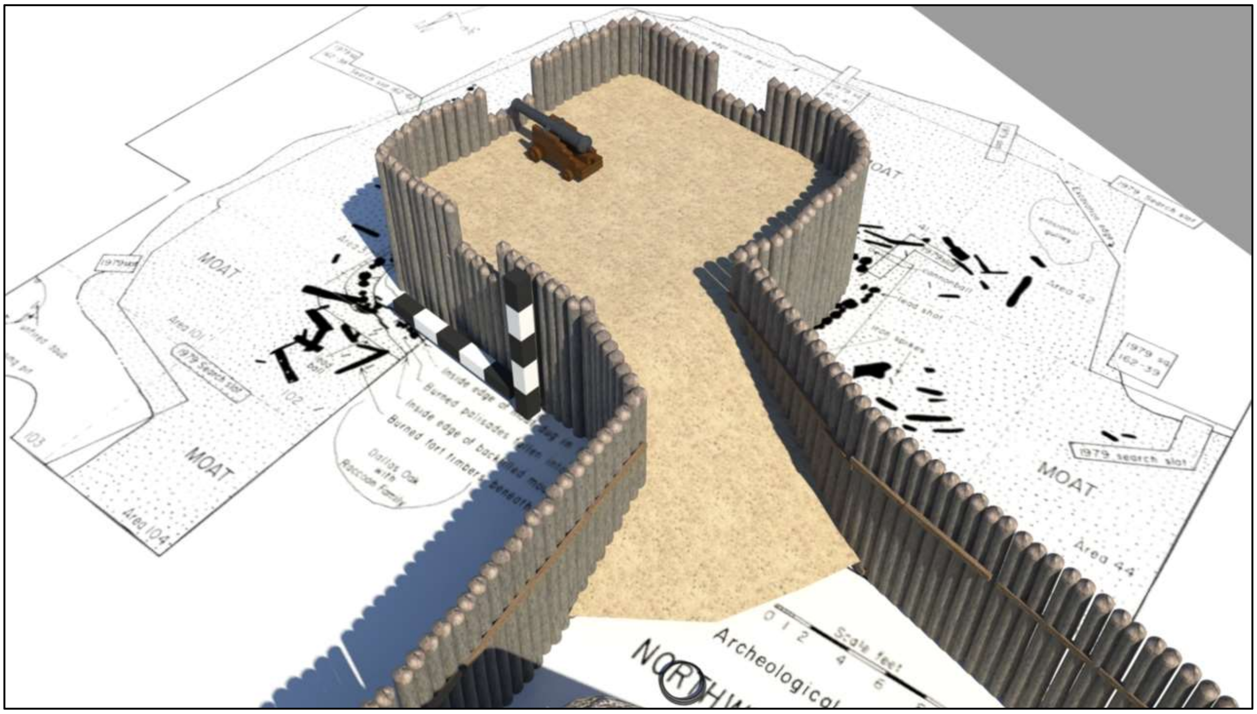

Figure 6.20: Bastion with ramp access.

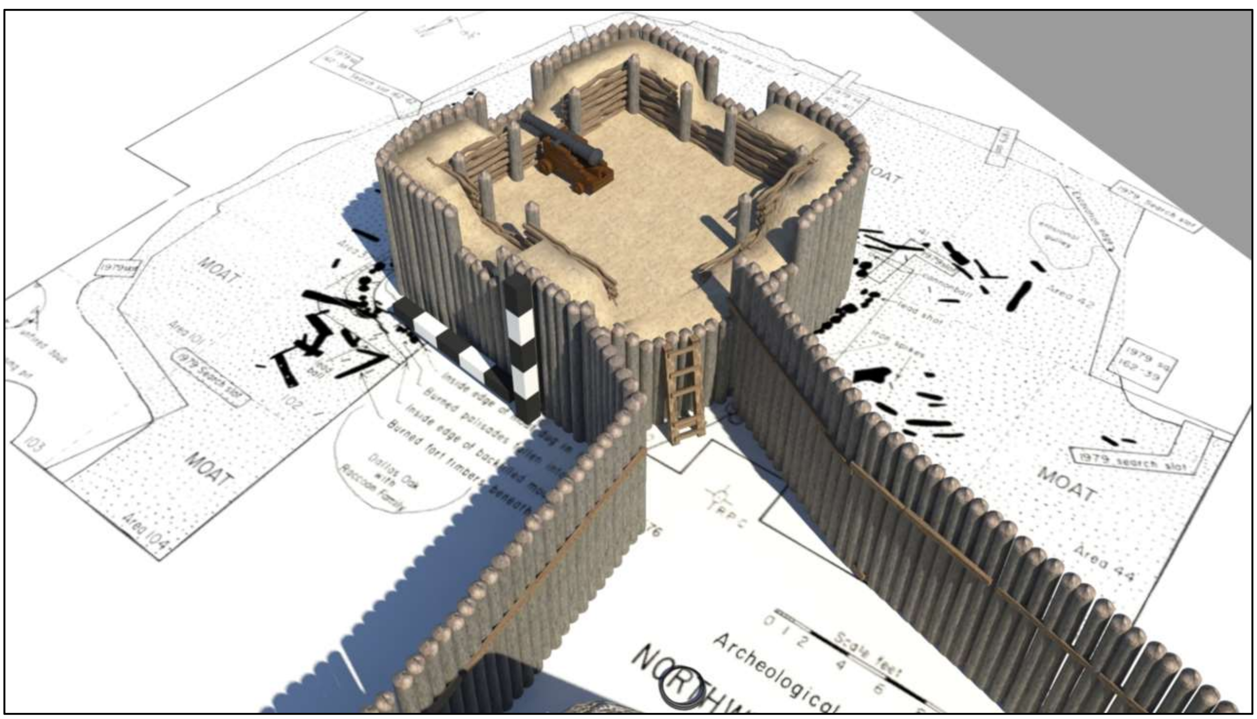

Figure 6.21: Bastion with embrasures supported by fascines.

The archaeological reports appeared to leave the question about the location of the fort entrances unanswered. Initial review of the fort's well excavation suggested that the water table is less than 3 feet below surface, so figure 6.22 shows water in bottom of the moat. But this raised the question of whether erosion of the sandy soils into the moat would have made the bottom dry.

Figure 6.22: Reconstructed fort with preliminary environment.

To further the effort, Versar sent the initial model renders to Professor Chester DePratter at the University of South Carolina, one of the principal archaeologists to work on the site since the 1980s. Dr. DePratter was impressed with the renders, but indicated that much of the thinking about the site had changed since the time the technical reports were published. Versar made arrangements to meet with Dr. DePratter in person, to go over the model, field maps and drawings, and discuss new thoughts concerning interpretation of the documentary record.

The principal focus of the meetings was to review historical documentation, including period maps, which suggest an alternative interpretation of the archaeological results. The most significant piece of historical evidence involves a sixteenth-century plan drawing of a fort that resembles the outline of the fort found at Santa Elena (Figure 6.23). This plan is labeled as describing a fort at Spanish Saint Augustine, but the plan view is not consistent with any of the Spanish forts known to have been at Saint Augustine. This raises the possibility that the drawing was mislabeled, and actually depicts Fort San Felipe at Santa Elena. Another change regarded the original interpretation of posthole features within the fort as a pair of Casas Fuerte (strong houses). Chester DePratter now believes it is possible that these may be the remains of the settlement church known to have been built by 1569 (DePratter personal communication 2015). Figures 6.24 through 6.27 reimagine the fort model using the plan in Figure 6.23 as a point of departure, and following the interpretation of Spanish Colonial architecture offered in Manucy (1997) as a guide. There is now some question about how to interpret the features thought to be remains of the village (South 1996; DePratter personal communication 2015). For this reason, the village has been left out of some of the renders, and where it is shown, it is shown as partly transparent in order to convey the uncertainty.

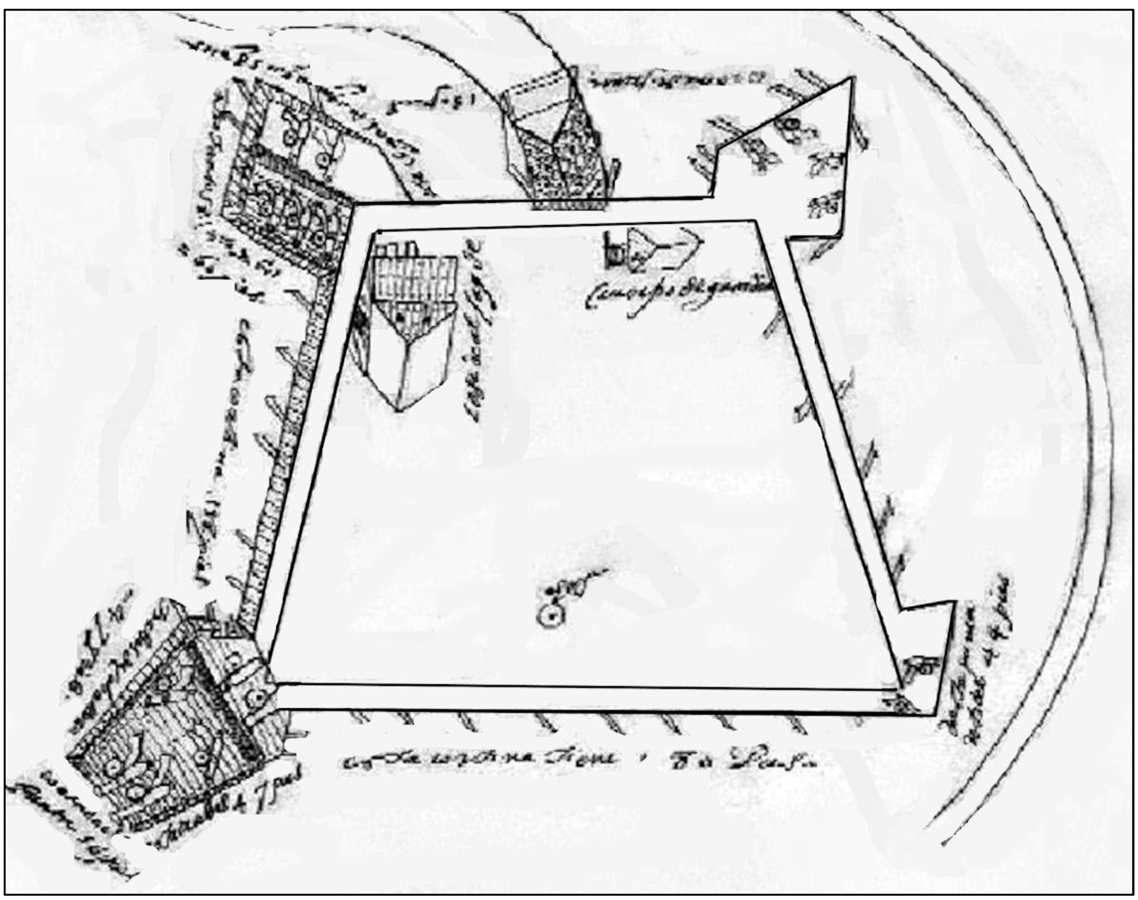

Figure 6.23: Possible plan view of Fort San Felipe. Library of Congress.

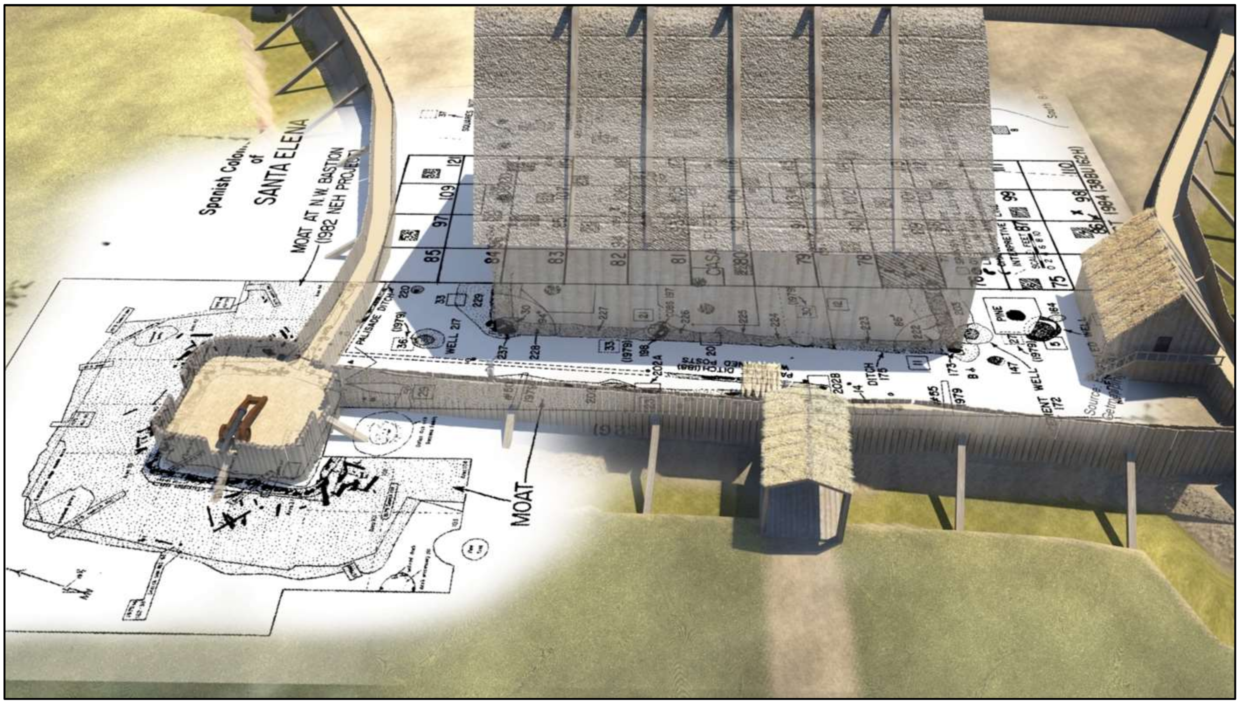

Figure 6.24: Fort San Felipe ca. 1572 with archaeological plan maps. Water has been removed from the moat, since closer examination of the archaeology suggests it was dry.

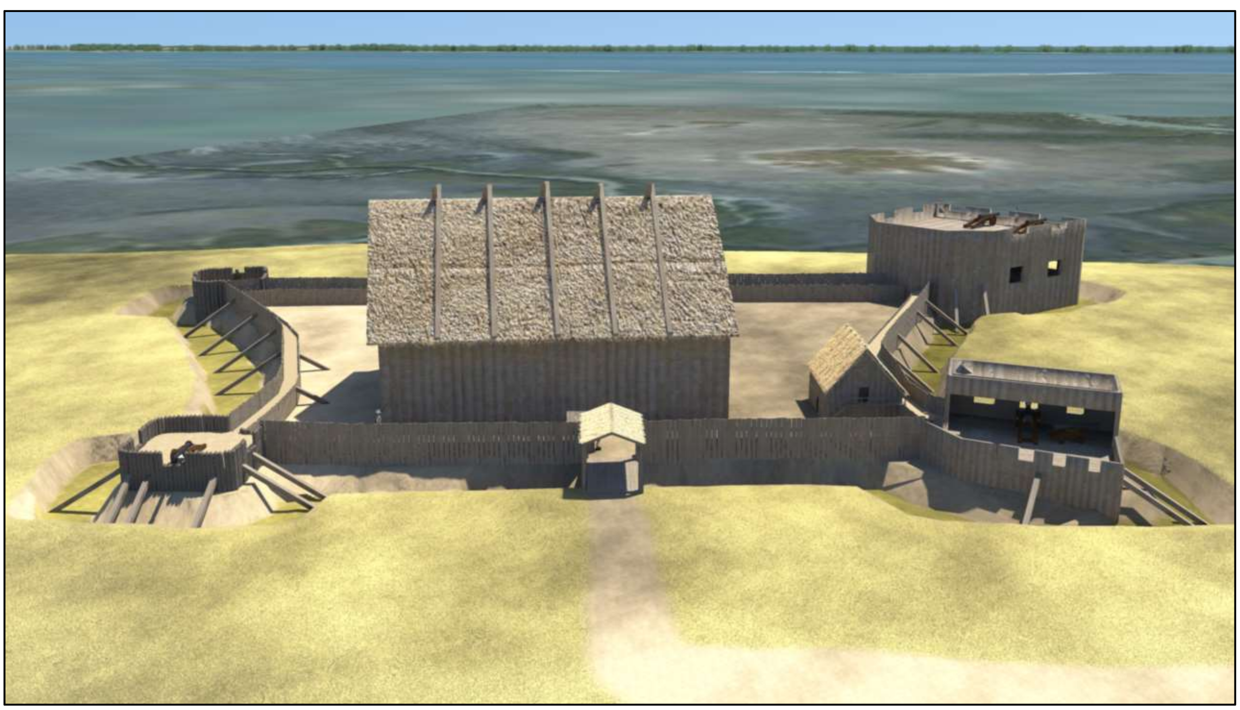

Figure 6.25: Fort San Felipe ca 1572, facing east.

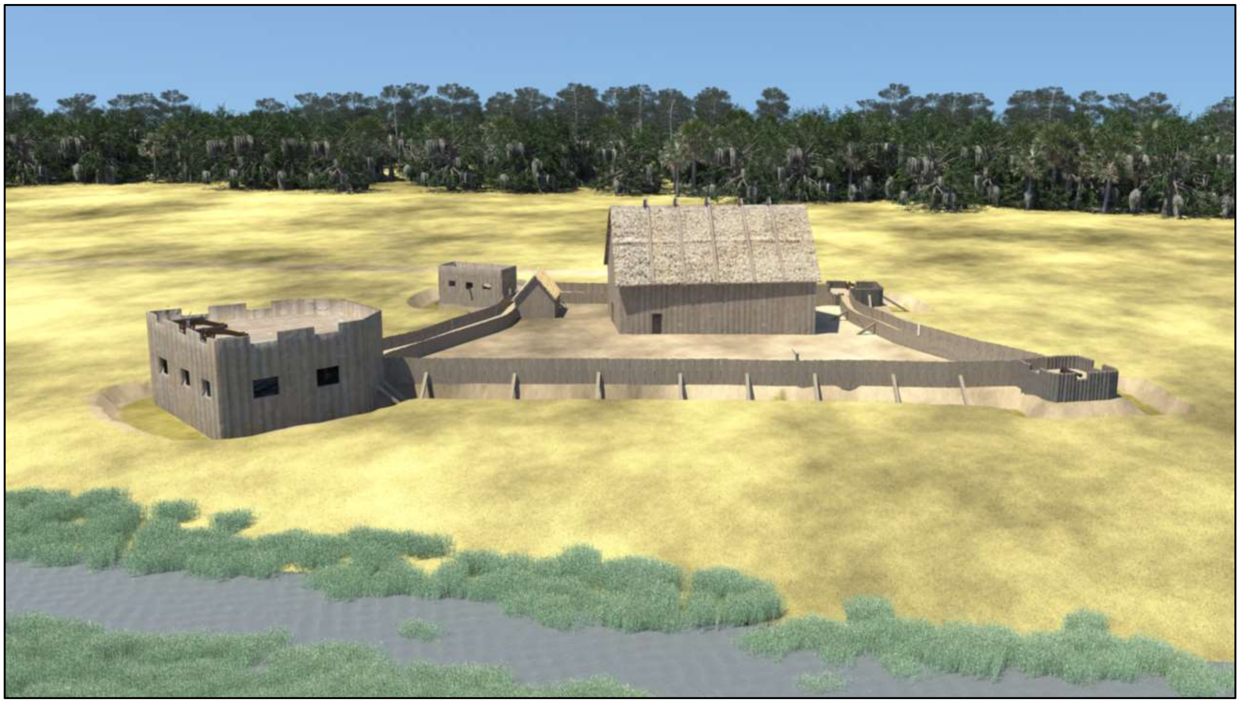

Figure 6.26: Fort San Felipe ca 1572 facing west.

Figure 6.27: View facing south, with hypothetical village shown partially visible.

The visualization products were prepared with the London Protocols in mind. They consist of a variety of products supporting a range of interactivity, but not requiring users to install new software. Several of the still renders combine the virtual model with imagery from the archaeological plan data. In addition to the still renders shown above, and in Section 3.2, there is a video file with a camera that slowly circles the final version of the fort model. This allows the viewer to see the model from all angles. Three 360 degree panoramic renders have also been prepared that allow a viewer to look in all directions from three vantage points using a web browser.

Creating these models offered a number of possible lessons regarding interpretation of the fort. South (1996) includes period drawings of sixteenth-century fortification methods, including some with sloped parapets. But in creating the model based on the archaeological findings, it became very clear that the bastions were too small to allow room for sloped parapets or field-type cannon carriages; the walls needed to have been vertical, and probably the cannons would have been mounted on small, naval-type carriages. The fort plan shown in Figure 6.23 appears to include what may be dimensions for some of the walls. Modeling the southeast castillo using the apparent measurements produces a structure improbably large for the location, while using the proportions suggested by the drawing itself appears to fit the probable landform better.

Although substantial archaeology has been conducted on the site, much remains unknown or uncertain, and more adjustments to the interpretations shown here may become necessary as more of the site is explored. There is also the possibility of recreating later phases of the site's occupation, including possibly two versions of Fort San Marcos and the associated village. Archaeological digs have also found evidence of the WWI era Marine Corps camp. This evidence together with contemporary photographs and engineering plans may make the WWI occupation a possibility for interpretation.

6.3 Application of Best Practices

6.3.1 Define Project Goals

This was a demonstration project, designed to support the initial development of best practices and provide illustrative examples of the kinds of processes and end products available to cultural resources managers interested in 3D visualization.

Best Practices

- Consult as early as possible. Include the public and other interested parties such as associated descendants or veterans groups. Because this was a demonstration project, consultation was internal to DoD. Should similar projects be contemplated as part of NRHP compliance, it will be necessary to broaden the consultation audience at the outset.

- Consider the nature of subject resource (condition, location, future plans).

  Building 8 is an extant building for which detailed plans of current conditions are available. The surviving fireplaces provided an opportunity to demonstrate the use of photogrammetry for recording and sharing such features. The extent of modifications to the second floor, and the availability of an existing 3D CAD model made optical recordation methods for this part of the building redundant and impractical. CAD modeling of elements indicated by a historical photograph allowed virtual recreation of the space as it may have been configured in 1917.

  There are no visible extant features associated with sixteenth-century Santa Elena remaining at MCRD Parris Island, making CAD reconstruction from historical and archaeological sources the only options for virtual recreation.

- Evaluate the project goals and methods according to the London Charter for the Visualization of Cultural Heritage.

  Reviewing Principle 2 of the London Charter suggests that Building 8 and Santa Elena are good subjects for virtual reconstruction. Both are highly significant properties where it may be difficult for a modern visitor to experience or appreciate how those properties appeared in the past. Substantial evidence exists on which to base a reconstruction.

6.3.2 Define End Products

The end products for this demonstration project were chosen to show a range of possibilities that do not depend on specialized software for the end user.

Best Practices

- Consider a balance between level of effort, accuracy, ease-of-use, and degree of interactivity.

  In this case, the level of effort available was relatively modest. Given the nature of the subject resources, the end results were planned to relate more to outreach and interpretation rather than recordation or engineering applications.

- Determine from stakeholders the range of potential uses for current or follow-on projects such as HABS/HAER recordation, effects determination, asset management, or public outreach.

  Given the focus on interpretation, still renders, an animated movie, and 360 interactive renders were produced because these represented a good trade-off between interactivity, ease-of-use, and available effort.

6.3.3 Choose Technology

What technologies will be needed to create the visualization followed from defining what the specific end products will include.

Best Practices

- The technologies employed (optical recordation techniques or CAD modeling for example) should produce accuracy needed to support defined project goals, but it may not be good practice to exceed those needs.

  Most of the visualization work was done with Maya since the emphasis was on recreating environments that are no longer extant. Photogrammetry of the fireplaces provided an example of optical recordation and 3D pdf files as an end product. Since documenting the accuracy was not required, and the available level of effort was modest, photogrammetry made a better choice for this than laser scanning.

6.3.4 Document

This report documents the project goals, technologies chosen, and methods employed. The results of associated historical or archaeological research are discussed.

Best Practices

- The technology employed for recordation, and steps taken in data processing should be documented.

  Sections 6.1 and 6.2 include discussions of the technologies employed, and processing steps taken.

- The sources used and potential uncertainty in virtual reconstructions should be incorporated into the visualizations themselves as well as described in accompanying text.

  Archaeological maps were incorporated into the renders of the virtual Santa Elena Model to help show the relationship between the model and excavations published so far.

6.3.5 Curate

Providing for curation for digital products associated with archaeological projects on federal land is a requirement of 36 CFR 79. Even when archaeological sites or projects are not involved, data curation should be considered an important best practice in order to avoid potential loss of valuable cultural resources program investments.

Best Practices

- Consider including open-source or highly portable file formats in deliverables.
- Visualization technology is a rapidly evolving field; installations may wish to avoid rigid file specifications in a scope of work, asking that vendors instead specify in their technical approach how they will address issues of future access.

  Although archiving digital data produced was not part of the scope of this demonstration project, where possible open-source or widely used data formats were adopted. The photogrammetry scans of the Building 8 fireplaces were saved in obj and 3D pdf formats. Renders from the models were saved in jpg, mp4, and html formats. The CAD models are available in their original mb file format, as well as the more portable fbx format.

6.4 Looking Forward

As the use of 3D visualizations within cultural resources management practice continues to grow, the DoD may wish to take steps to ensure that its data are curated for long-term preservation, and capture lessons learned in order to maximize the benefit of such projects to the services and the interested public. Use of the protocols and best practices outlined in this document will help maximize the benefit and cost efficiency of future projects making use of 3D visualization for recordation, condition analysis, effects determination, research and outreach. Making end products from visualizations available from a centralized archive (such as tDAR or similar if available) will allow comparison of results achieved. This in turn will make it possible to update and refine the protocols and best practices described here. In particular, enhanced outreach through effective 3D visualization will help DoD promote and interpret the cultural resources under its care and increase support for conservation efforts.

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